SCIENCE IN EDUCATION

By the same author

Modern Glass-Working
Simple Experiments in the Theory of Flight
(*Heinemann*)

SCIENCE IN EDUCATION

by

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FOREWORD

By

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Scientific Member of the National Coal Board

I am honoured to have seen this book in proof and to have the privilege of contributing this foreword. Mr. Nokes has a high sense of purpose and he believes, and many will agree with him, that the hope for the future lies in the education of young people. In this education science must play a large part, and it is to the examination of this participation that he addresses himself, both as a widely read scientist and as a professional teacher.

The time is appropriate for such a study. We are reminded daily in the newspapers of the achievements of science; we are exhorted to believe in science to an extent that almost suggests it is the one possible magical solution of all difficulties. The word science is becoming one of the more widely used in our language, yet how few have even the vaguest conception of what the term should mean.

The author writes as an enthusiast, and with no equivocation sets out his point of view. He has drawn his pictures in bold lines, and takes his stand with no attempt to shelter behind vague statements. This book will give rise to controversy, but it should be honest and helpful controversy.

Mr. Nokes says that he has written primarily for teachers, and to all these I commend his book warmly, but I wish too that our leaders, both in industry and politics, could find the time to read this valuable study of the thing on which they willingly or unwillingly spend so much money.

AUTHOR'S PREFACE

There is to-day a greater need than ever for the exercise of reason in human affairs. Only by this means will it be possible to make efficient use of the power which has been put into our hands by science. In addition, an emphasis on reason during the period of formal education will promote the making of wiser judgments than have commonly been made in the past, particularly of those influences which are brought to bear upon us all by propaganda.

This book is intended primarily for teachers, or for those who intend to teach. It is written at a somewhat elementary level, and it is suggested that the details of the picture which is presented here should be filled in by supplementary reading. Its author has a dual aim. The first is to give a simple account of the methods used in the sciences. It is in large measure the application of common sense to the solution of the problems which arise in the study of nature, coupled always with an insistent demand for evidence, that has produced a revolution in the way of living in the course of a few hundred years. It is important to understand why the method of science has been successful in its own field. The second aim is to show how it is possible to sort out those problems which can be solved by the application of reason from those which require treatment by some other method, such as the making of value-judgments. That the attitude of reason is implanted in us all to some degree is not in doubt; it is suggested that an important educational aim should be to strengthen and amplify this attitude, so that it can be called up in those situations which seem to demand its use. Bound up with the advocacy of reason as an attitude towards our natural environment, and also towards our fellow-men, is the subject of communication by means of language.

Since the function of the teacher is the accurate communication of his ideas to his pupils, some space has been devoted to this question, for the dissemination of reason demands the accurate transmission of meaning from person to person. It is contended that the problem of communication in science is relatively simple, and has substantially been solved.

The range of literature which bears on these subjects is large. Writings on scientific method, logic, metaphysics, psychology, and semantics have been consulted, and where conclusions have seemed to be both pertinent and well established, they have been quoted or incorporated in the argument of the book. A short bibliography of easily accessible books is included.

It is not possible to make individual acknowledgments to all the writers who have influenced the growth of the author's opinions, but where specific quotations have been made in the text, the works from which they have been taken are referred to in a footnote. My sincere thanks are due to the publishers for their advice and consideration at all times during the preparation of the book.

M. C. N.

Harrow on the Hill,
April, 1948.

CONTENTS

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SCIENCE IN EDUCATION

CHAPTER I

WHAT IS SCIENCE?

TWO THINGS were sufficient to fill Immanuel Kant with ever-renewed wonder and awe: these were the starry height above him and the moral law within him. The first, he says, arises from his position in the outer world of the senses, and the second arises from his invisible self, his personality. It is convenient to accept this dualistic picture at the level of enlightened common sense, as it gives the key to the nature of science. No purpose would be served here by attempting to follow the probings of those philosophers who feel bound to reject this dualism, for to do so would lead us too far afield from the subject of this inquiry. And, although Bishop Berkeley would have disclaimed this view, it seems that when he speaks of "the whole choir of heaven and furniture of earth", he is tacitly supporting the naïve dualism of the ordinary man who holds that mind and matter are of different kinds.

The contemplation of the heavens gave Kant a realization of the setting in which his personality was free to operate. Had he been more inquisitive about his surroundings, and had he lived in our time, he would have found many more phenomena, no less wonderful and no less awe-inspiring, than those he names. He was neither privileged to witness the intricate details of the division of a living cell nor the unexpected behaviour of liquid helium. The starry depth of Crookes's spinthariscope was undiscovered in his time; no man had yet seen the tracks of a shower of alpha-particles which, meteor-like, shoot across the Wilson cloud-chamber and are gone. Such spectacles and many more like them can

hardly fail to impress the inquiring mind; nor are such wonders to be seen only in our laboratories, for the adaptation of many of them to practical life is commonplace to-day.

It is with the furniture of earth that science is concerned. The stars, perhaps, must be regarded as furnishing an annexe rather than the main building which man inhabits, but the evidence leads us to believe that the stars are made of the same stuff as the earth is, and both seem to be subject to many of the same laws. The stars are made of matter and, as such, are suitable for scientific contemplation. In addition to the furniture of earth, human personality obtrudes itself upon our notice; we speak of the realm of values; of the desires and emotions of men; of judgments of right and wrong actions; of loves and hates; of concepts of good and evil; of beauty, faith and courage. All these constitute a non-material medium in which man finds himself immersed simultaneously with matter, but about the realm of values science has nothing to say. Science is completely non-moral and ethically neutral. Its findings are neither good nor bad, but because of the use to which its findings may be put, it is sometimes applauded as the great deliverer from human toil or pain, and at other times is execrated as the source of all our ills. Such judgments as these are not about science at all, but are about the actions of the men who make use of it. Value resides not in the machine, but in the purpose for which it is used. A sword or a dagger is not an evil thing in itself; indeed, by reason of its achievements as the champion of right, the sword has become the symbol of the concept of justice, of which we all approve. None will deny that the large fortune of the late Alfred Nobel was amassed by the use of scientific method and the application of scientific discovery to the manufacture of high explosives. Few will deny the evil purpose to which his discoveries have been put; but it is far easier to appreciate that the discovery of high explosives is in itself neither good nor evil, than to relish the sardonic situation which has arisen by his foundation of an annual prize to the value of several thousands of

pounds to be given each year to that statesman or other person who, in the opinion of the Norwegian Storthing, has done most to promote the cause of peace. Science, then, in its practical applications, is no more than an instrument of the purpose of man, which purpose may be good or evil. The weapon which is used to slay the man-eating tiger becomes an evil thing in the hand of the assassin.

It must not be thought that science is concerned only with technology, or the production of instruments for the control of our environment, although this is its obvious field of application. Agricultural processes, mining, manufacturing, cooking and medicine, have been carried on from very early times by means of common-sense and the method of trial and error. Discovery and invention have improved these processes and, since the advent of science, many further improvements have been made in them by the purposeful application of scientific principles and discoveries. But this use of science is only incidental to its growth and is an accretion upon it. The underlying body of scientific doctrine has been built up for quite a different purpose by persons with qualities of mind different from those who have concerned themselves mainly with improvements in the paraphernalia of civilisation. Nevertheless it is the practical applications of science, which are known to all, that have so impressed the non-scientist. Yet it is true that in the course of years even the most recondite scientific theory may come to influence the lives of common men; for science has contributed to the building of the unexpressed background of life and to the moulding of the relationship in which man feels himself to be towards his natural environment, once thought to be hostile, inexorable or capricious. These two purposes, interwoven under the single name of science, must be dissected to reveal their constituent factors and to make possible an estimate of the part that science can play in human life.

The word science, as understood in connection with education, refers to a certain body of knowledge. As Professor Wolf puts it, "Science is a species of theoretical knowledge."[1]

[1] Wolf, A.: *Textbook of Logic*, p. 26 (Allen & Unwin).

The word "theoretical" is important in this definition. Science is not a craft, nor is it a practical skill. A scientist may contribute to the body of scientific knowledge without himself carrying out any practical experiments, without constructing any apparatus or even without making any observations. It may happen that others will carry out these necessary tasks for him, although he will usually wish to make observations for himself. His special function is intellectual. It is usual for a scientist to design the apparatus for his experiments, but this is not a necessary part of the scientific activity. Much original work of the greatest importance has been done with quite simple things. At other times more complicated apparatus has been required, but it is not necessary that the construction of it should be carried out by the scientist himself. He may employ a mechanic for this work. In the early days of the Royal Society of London, Robert Hooke was employed to construct apparatus and to carry out experiments with a view to testing the ideas of the members of the Society. It is said that J. J. Thompson was not himself a constructor of apparatus, although he had much apparatus made to his design, and he was one of the greatest of scientists.

Astronomers do not always make their own observations. Neither Adams nor Le Verrier was the first to see the planet Neptune, although they had told others in what region among the stars it was to be found. The practical verifications of Einstein's relativity theory of gravitation were not made by Einstein himself. The first, the discrepancy in the orbit of Mercury, was an old observation which had long troubled astronomers; the second, the bending of light as it passes the sun, was observed by two expeditions of English astronomers; and the third, the observation of the shift towards the red end of the spectrum of the light from a dense star, was first carried out successfully by an American at the Mount Wilson Observatory in the U.S.A.

Although most scientists possess manipulative skill in addition to their intellectual faculties, many other instances

could be quoted of one man doing the thinking while others have carried out the practical work.

Let it be granted then that science is a species of theoretical knowledge. It remains to determine the species. A consideration of the main branches of science, astronomy, physics, chemistry and biology, at once makes it clear that the knowledge is of the external world. The material contemplated by the scientist consists of such things as the heavenly bodies, the rocks, the sea, the air, animals and plants. We all have some knowledge of these things, which may be called *ordinary* knowledge. It is acquired in the pursuit of our ordinary everyday affairs, and is not what is meant by scientific knowledge, the peculiar feature of which is that it is gained by a special method and is used for a particular purpose. This purpose is to explain or to account for natural events. The secondary purpose of exploiting natural events, which has given rise to the vast growth of technology, is less fundamental. The method is called the scientific method. Science, then, is theoretical knowledge of nature gained by a special method.

There are many natural happenings which have proved not to be susceptible to investigation by the scientific method, such as some of the events which occur in haunted houses. Events in our minds must be described as natural, but much difficulty has been encountered in applying scientific method to them, and, as a result, the science of psychology, or knowledge of the mind, is not nearly so far advanced as physics, which is concerned, let us say, with matter. The special feature of scientific method is that its observations must be of such a kind as to be capable of eliciting universal agreement. They must be of verifiable facts untinged with opinion. On these facts a superstructure is built with the idea of explaining natural events in familiar terms, or, in some cases, in mathematical language.

The use of measurement, the quantitative treatment of natural events, is most important for the progress of science. Those sciences which are most easily able to use the quantitative method, so that the data obtained by observation

can be treated with the aid of mathematics, are those which have made the greatest progress. Astronomy, physics and chemistry are examples of these. The value of the quantitative method of treating data is that certain aspects of the behaviour of things are thereby simply described as conforming to simple patterns, called scientific laws. The establishment of these laws, which are summaries of the modes of behaviour of natural things, provides a foundation on which the great explanatory generalisations, or theories, of science can be built: gravitation theories, evolution theories, kinetic theory, quantum theory, are examples. The formulation of such theories as these constitutes the crowning achievement of the scientist. It must be understood that these theories can be accepted only when they have been rendered plausible by the results of experiments, and that they are always susceptible of modification, or even of overthrow, in the light of fresh experimental results which conflict with them.

Thus, the method of science consists first of observation, either of natural events or of experiments which have been contrived, with a view to classification, or to the establishment of laws which are, if possible, quantitative. Then comes the construction of broad explanatory generalisations, called scientific theories, which are accepted only after the most rigorous tests have been applied to show that they are at no point contrary to experience.

The scientist is known by the purpose and direction of his thinking, for thinking is the essential scientific activity. Acuteness in observation and skill in craftsmanship are valuable accessories, since they are the means to the collection of fresh data for the thinking process. Skill in mathematics is also an important aid to scientific thinking, but none of these three is more than a tool in the hand of the scientist. His function is intellectual: it is the interpretation of phenomena.

Popular notions of what science is are very varied. Possibly they all contain a grain of truth, and a synthesis of them might give a picture of the subject as a whole.

Among the uses to which the word science has been put are these:

(1) Science is a body of knowledge.
(2) Science is the meaning contained in certain text-books and periodicals.
(3) Science is a collection of laws and theories.
(4) Science is an activity: it is what goes on in laboratories.
(5) Science is a method of gaining knowledge.
(6) Science is measurement.
(7) Science is a magic password, useful in advertising and for delivering a knock-out blow in argument.

Because a number of technical problems have been solved by science, it is also thought to be some kind of panacea, a power of universal applicability, which has only to be suitably invoked to solve any problem of health, production, distribution or government. The success of science in its own field is in fact no guarantee that the same method will be successful or even applicable in other fields of human endeavour.

Matter and Space. Matter has a number of properties by which we can recognise its existence. It has *extension*, or occupies space. This property serves to distinguish it from mind, which usually seems to be associated with matter in the form of brain-substance, but mind cannot be measured in terms of length, area, or volume. A course of physics usually starts with instruction in the methods of measuring the extension of portions of matter, or of finding out how much space bodies occupy.

Another property of matter is *mass*. We say that it is necessary to exert force upon a body in order to move it, and we find that it requires more force to move a large piece of iron than a small one. Further, if we have a wooden ball and an iron ball of the same size, we find that it requires more effort, or force, to throw the iron ball, say, twenty feet, than is required to throw the wooden ball the same distance. The property of resistance to motion possessed by the iron and wooden balls, and indeed by all matter, is called

mass. Although the sizes, or extensions, of the iron and wooden balls are the same, their masses, as known by the forces required to move them equally, are different. All bodies at the earth's surface are acted on by the force of gravitation, which force, acting on a particular body, is called the weight of that body, and weights are found to be proportional to masses. We can therefore recognise matter by the effect of gravitation upon it; that is, by the fact that it has weight. We talk of "ponderable matter", and an introduction to the study of physics includes practice in the determination of the weights of bodies.

Ponderable matter is of two kinds, living matter and non-living, or inanimate, matter. Living objects go through a life-cycle and are capable of reproducing their kind. The branch of science which deals with them is biology, but, in spite of its obvious importance to man, biology cannot be regarded as the fundamental science. That position is held by physics, which deals with those aspects of phenomena which are common to all natural objects, and all branches of science seek to describe their subject-matter in terms of physics. The great success of the physical sciences has been due to the application of the method of exact measurement, as in astronomy, which is concerned with physical processes occurring on a cosmic scale, and in chemistry, which is concerned with the physics of atomic combinations. Biological material can be treated to some extent by the method of physics, but many biological investigations require the isolation of matter from the organism, with the result that, when investigated, the matter is no longer living, but is dead. The method of exact measurement is applied with difficulty in a field for which it was not designed.

Matter is encountered immersed in an all-pervading medium called *space*, whose most striking property is that it brings portions of matter into relation with one another. These relations are known, in a general way, as gravitation, heat, light, magnetism and electricity. Because of our habit of trying to picture the unknown in terms of the known, attempts have been made to regard space as having properties

like those of matter, but such efforts are doomed to failure because it is by reason of the differences between matter and space, rather than of any property common to them, that we infer the existence of space. To try to think of space in terms of matter leads to contradictions and is therefore to be avoided. Space does not possess mass, and some new way of conceiving it is necessary. To-day a beginning has been made to frame these new conceptions, but the task, which is perhaps the next great goal of physics, is a formidable one. Nevertheless, the progress that has been made in the investigation of space is leading to the conclusion that space and matter are somehow interdependent. According to the relativity theory, space in the proximity of matter has a special curvature, but ideas on the relations of space and matter have not yet fully matured. The subject requires mathematical treatment, and is therefore unsuitable for simple discussion.

Since science is a construction of the human mind and is concerned with matter, it must be the result of and depend upon human experience of the outside world. It is our senses which divide what is knowable into ourselves, the perceivers, and the outside world. We are somehow conscious of our own powers of comprehension. We know that we know. Integral with the knower is an object which is external in a special sense. It is our own body, parts of which can be seen and felt. The knower commonly assumes that his body is the seat of his sensations, and that it persists when he is asleep or unconscious. He argues that the external world consists of many other objects which persist in time, some few of which are similar to his own body and are associated with minds which know that they know, like his own mind. These objects are his fellow human beings. Nothing is to be gained from the point of view of this inquiry by questioning this common-sense account of the existence of other minds. The distinction we have to make is between the different kinds of experiences which minds can have, for, presumably, all experiences of the outside world might be the subject-matter of scientific investigation.

It is well known that many experiences which we have in common cannot at present be treated by the method of science, such as, for instance, our enjoyment of poetry or music; nor is it difficult to see why this should be so. Although we all draw upon the common stock of stimuli provided in the outside world, my own experiences are private, in that they are constituents of my consciousness. If I am eating a dish of beefsteak, I may have sensations of a coloured patch before me, of an odour, and of the taste and texture of the food in my mouth. When I share my meal with another person, I can never be quite sure that he enjoys sensations which are identical with mine. There is no satisfactory way of comparing or communicating our sensations of feeling, colour, taste or smell. The same difficulty arises when we attempt to assess tonal quality. Such sensations can be used as approximate guides to the identity of things, as far as the subtleties of language allow, but the descriptions of them are not sufficiently precise for most scientific work. A type of sensation is required about which agreement can be obtained among a number of *bona fide* investigators. The scientist knows, as we all do, that there can be no universal agreement about dreams or hallucinations. Any informed person realises that his senses are fallible. He is also aware that there are sometimes persons who make use of this human trait and are interested in deceiving him for their own ends. Since the scientist wishes to have genuine experiences of the outside world, he must guard against both fraud and self-deception. The chosen sensation must be of the simplest and most trustworthy kind. He needs a kind of experience which will, in itself, evoke neither pleasure nor pain; it must be precise, so that it can be recorded for the purpose of communication to others; it must be possible to use it for recording a wide variety of natural events; and it must be an experience of a kind about which different people do in fact agree.

The sense of sight is quite fundamental in our ordinary lives, and is the one which fulfils the requirements mentioned above. We use it, among other things, to make what

may be called geometrical judgments. We often arrange the objects in our houses with a view to securing symmetry. We hang our pictures with their horizontal edges parallel to the floor. We are easily able to judge a perpendicular, and whether two lines are parallel. Above all, we can say instantly when two objects lie in our line of sight, or whether one of them is to the right or left of the other. Thus, it is easy to judge by eye when two narrow objects, such as two pins, are collinear, or nearly so. Universal agreement can readily be obtained in situations of this kind, and, in consequence, many of the judgments employed in scientific work are founded upon such geometrical ideas.

Most measuring instruments are designed so that a sharp pointer or its equivalent, which is capable of movement, comes to rest when overlapping the markings of a scale. The "reading" is made at that position in which coincidence, as judged by the eye, occurs between the line of the pointer and some line on the scale. Thus the sense of sight is the fundamental sense, and the judgment of coincidence in space, or apparent continuity of line, is the fundamental judgment. The exact sciences are those which are able to make full use of this method of measurement and much ingenuity is displayed in reducing events, which we ordinarily notice as sounds or movements or colours, or which are so minute as to escape our unaided observation altogether, to the coincidence of two lines upon a scale. It is for this reason that Eddington stresses the importance of pointer-readings as the fundamental data of science.[1] It may be said that the concern of science is with those judgments of sensations about which universal agreement can be obtained. This criterion of the subject-matter of science serves to distinguish it from those other activities of the mind with which it might be confused. Universal agreement can also be obtained about the judgments of mathematics and, to a lesser extent, of logic, but both these classes of judgments are about thoughts or abstractions, not about sensations and are therefore not the subject-matter of science, although they

[1] Eddington, A. S.: *New Pathways in Science*, p. 13 (C.U.P.).

may be used to assist in understanding that subject-matter once it has been acquired by the observation of nature.

Scientific Method. The startling success which science has had in controlling natural processes and in predicting the future course of events has led to a very thorough investigation of the method used for attaining these desirable results. This dissection has given rise to a picture of scientific method which may be summarised as follows:

(1) Realisation of the problem and the attempt to solve it
(2) Experiment and observation
(3) The framing and verification of laws
(4) The attempt to understand and explain the phenomena under review.

Realisation of the Problem and the Attempt to Solve It. Sometimes a scientific worker turns his attention to an old problem, such as that of the function of the animal heart, of which no satisfactory account had been given until the time of William Harvey in the reign of James I of England. Sometimes a striking and entirely new observation is made, such as the discovery of X-rays or of radioactivity. More often the work of the scientist is less picturesque and spectacular. His work may give the appearance of drudgery to the uninformed, and may in fact consist of repeating the work of another investigator in order to verify his conclusion, or in carrying out a series of measurements with a greater degree of accuracy than has been done hitherto. Whatever the task may be, the scientist has first to realise that a problem awaits solution. He then makes an attempt to solve the problem, usually by means of a conjecture as to the course of events which led up to the problem-situation or which may follow from it. This process is the framing of a hypothesis. It comes at the beginning of a scientific research. The worker must have some idea of the possible or probable course of events, and must make his plans and dispositions accordingly. He devises apparatus, the observation of which will, he thinks, reveal those invariable relations between

the qualities of things which it is his aim to establish. He must hit upon a fruitful line of action, overcoming difficulties as they arise. Some men seem to have a special faculty or flair for choosing a remunerative line of approach to a problem. They have insight into the working of phenomena which prompts them to attempt just those experiments which will yield useful and relevant results. The power to do this may be called the scientific faculty, and is a gift like that of linguistic ability, or of the ability to run faster than others. It can be improved by taking pains, and by an increase in knowledge of the workings of nature, but there are many people whose interests lie in quite other directions, and who therefore do not seem to possess it. As in the case of the artist, so in the case of the scientist; there is no substitute for talent. Newton, Faraday, Rutherford and many others have solved problems which have baffled their contemporaries because of an innate capacity for framing fruitful hypotheses. They had a special kind of mental adroitness, which is successful both in devising a plan of action and in designing the very apparatus which is profitable for solving the problem in hand. Not only are such men fertile in the invention of hypotheses and resourceful in the face of difficulty, but have frequently had a well-nigh incommunicable skill in the selection of a line of conduct when alternatives present themselves.

Experiment and Observation. Experiment is an essential feature of most of the sciences, but it is not by any means used by science exclusively, for the experimental method is employed in many other practical activities, such as, for instance, cookery, in which experiments are made in the heating of foodstuffs with the intention that a palatable product shall result, or in fishing, in which experiments are made in ways and means of luring aquatic creatures into captivity. Scientific experiment, which is carried out with the object of discovering invariable relations between the properties of things, is necessary when the crude phenomena fail to reveal the required relations. The processes of nature are not commonly presented to us in a form which lends itself

to detailed observation or to measurement. Phenomena of interest have often to be disentangled from accompanying processes which obscure the relevant effect, or else the change to be investigated is so slight that a modification of the conditions of its occurrence is necessary to produce it in an intensity suitable for observation in the laboratory. Just as the chemist is unable to find invariable relations if his substances are contaminated with unknown impurities, so the physicist has to isolate phenomena in order to establish invariable relations by the observation and measurement of selected qualities.

Good examples of scientific method abound in the classical researches of the great investigators. Consider Harvey's discovery of the circulation of the blood, which was published in 1628. The physiologists of his time still taught Galen's complicated system of ebb and flow, in which the blood was thought to be formed in the liver and mixed with "natural spirits", some of it passing through invisible pores from the right side of the heart to the left, whence it was said to pass to the lungs and to be charged with "vital spirits". This did not satisfy Harvey as an account of the heart's action. He realised the existence of a problem and framed a hypothetical solution, using his accumulated experience and making new experiments to support the suggestion that the heart is a pump, that there are no passages in the heart through which blood can pass from the right side to the left; and that the blood reaches the tissues through the arteries, returning through the veins to the heart. There was thus a complete circulation of all the blood through the system. The merit of Harvey's work was that he produced evidence for his hypothesis derived from experiment. He estimated the amount of blood which is delivered into the aorta on each contraction and, from the rate of the heart-beat, he calculated that, in half an hour, a quantity larger than that of the whole of the blood in the body must have passed through the heart. Harvey thus introduced the quantitative method into physiology for the first time. That the heart is undoubtedly a pump he showed by experiments on the heart

of a living snake. When he compressed the vein leading to the heart, it became pale and empty of blood. When he compressed the artery leading from it, the heart became distended and suffused with blood. By these and other experiments he accumulated so much evidence as to compel attention. So clear were his experimental results and so cogent were his arguments that his publication of *Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus* soon brought about a revolution in the teaching of physiology. As the microscope had not been invented at the time of Harvey's work, he was unable to produce the final proof which his theory demanded. He was unable to demonstrate how the blood passed from the arteries to the veins in the tissues, but he put the fact of circulation beyond reasonable doubt. In 1661, the Italian microscopist Malpighi gave ocular demonstration that the blood passes from arteries to veins in the tissues through the capillary vessels which connect their ends.

There has been much controversy as to the originality of Harvey's work. It has been stated that some of the classical Greeks, or Leonardo da Vinci, or others, had forestalled him, but historians of science are not agreed as to the exact course of events. There seems to be no doubt that the idea of the circuit through the lungs had been entertained by several men before Harvey's time, and that Caesalpinus had thought that some blood passes from the arteries through the tissues to the veins, thus returning to the heart. But no one had secured evidence by experiment; no one had made out a convincing case, as Harvey had. Locy says: "Harvey's idea of the movement of the heart was new; his notion of the circulation was new; and his method of demonstrating these was new."[1]

It is not uncommon to find a situation in the history of science which is somewhat similar to the circumstances of Harvey's great discovery. When seen from the vantage point of history, it appears that from time to time there has been a convergence of intellectual interest upon a problem

[1] Locy, W. A.: *Biology and its Makers*, p. 51 (Henry Holt & Co.).

to which no clear solution has been forthcoming. Sometimes the question at issue has not been clearly formulated, or the possible lines of attack have not been adequately explored. Such solutions as are proposed are tentative or incomplete. Then there comes a change in the situation. A man arises who sees the problem steadily and sees it whole. He gathers up the threads of evidence, and by the exercise of what may be called his scientific intuition, he produces the unique acceptable solution. His arguments, though assailed, stand firm. The question of priority is perhaps of moment to the historian, but it is not of any particular scientific interest. The important thing is that a classic in the literature of science has been born.

Another research which has had a profound effect on the course of events, in that it made possible the rise of modern chemistry, is that in which Lavoisier settled the problem of the nature of combustion. Some things burn in air with a flame, and some smoulder without a flame. Some leave no residue, and some leave a residue which is heavier than the substance which was burnt. Are all these phenomena of the same kind and what part does the air play in the process? This was the question which Lavoisier set out to solve. Aided by the recent discovery of oxygen, in which substances burn much more vigorously than they do in air, he framed a hypothetical solution of the problem. He thought it possible that oxygen forms part of the air, and that combustion in air is nothing more than the combination of the combustible substance with this fraction of the air. He accordingly devised an experiment, using a known volume of air and a substance which not only is capable of undergoing a slow combustion when heated in air, but whose product of combustion is easily capable of giving back its oxygen to the experimenter. His choice of working substance and his experimental arrangements were fully adequate to provide evidence for his hypothesis. He confined a quantity of mercury, in the presence of a known volume of air, in an apparatus which could be heated and which could be made to show how much, if any, of the air was used up. After

heating the mercury for twelve days there was no further diminution in the quantity of air. He then collected the powder which had been formed on the surface of the mercury and heated it separately. The volume of pure oxygen produced was the same as the volume by which the air had diminished in the first part of the experiment, and the weight of the mercury was unchanged. His hypothesis was correct. Air is diluted oxygen. Combustion in air is the combination of the combustible substance with the oxygen of the air.

The reasoning processes used by Harvey and Lavoisier are such as might be employed by any human being. They were in fact easily understood by their contemporaries. There is no special way of reasoning which is peculiar to scientists and is known only to them. It is the direction in which his interests are turned that makes the man of science. It is probable that only a person interested in physiology would dissect a live snake in order to watch the slow pulsations of its heart. Only a person interested in the detailed workings of inanimate nature would heat a retort of mercury for twelve days. It is the purpose of these investigations which makes them scientific, coupled with the fact that the observations from which Harvey and Lavoisier drew their conclusions were of a kind about which universal agreement could be obtained. Detailed knowledge of natural events had been secured. In each case an obscure process of nature had been given a plausible and satisfactory explanation.

The Framing and Verification of Laws. The word *law* belonged originally to the universe of discourse either of jurisprudence or of ethics, in both of which it implies a rule of conduct attended by sanctions, a rule which is imposed by an outside authority. Although the same word is used as a technical term in scientific speech and writing, its meaning in this connection is quite different. Originally a metaphor, in modern scientific thought the word *law* has acquired a definite meaning of its own which is not easily confused with its other meanings. The method by which science proceeds is by the establishment of laws. These are carefully-

worded assertions that certain apparently invariable relations have been observed, or have been inferred to exist, either between events or between the properties of things. It may be stated here that by the term "thing" is intended either a perceptual object, such as a chair or a piece of sulphur, or, if the "thing" is not perceived directly, it is inferred to exist and to have a status in the outside world similar to that of perceptual objects. It might be difficult for those unacquainted with scientific technique to demonstrate that hydrogen is a "thing" in the sense of being a perceptual object. But a beaker of hydrogen can be poured into an upturned vessel suspended from the arm of a balance, and a visual effect can be produced which admits of the inference that there is a "thing" present which is lighter than air. Alternatively, the hydrogen could be introduced into a weighed evacuated globe, which would be found to weigh more after being filled with hydrogen than when it was empty. Bubbles of the gas can be collected over water. These bubbles burn with explosion when ignited, and so on. Simple inferences confer the status of perceptual object on the hydrogen, which we can neither see, nor taste, nor smell. Of course, hydrogen can be liquefied and solidified by means of suitable apparatus, in which states it can be directly perceived.

Other inferences lead us to classify certain particles, which are believed to exist but which are too small to be perceived, as "things". Such are atoms and electrons. These may be called conceptual objects. Their existence is inferred from observations of perceptual objects, but it is necessary to have certain theoretical ideas in order to make inferences of a kind which are acceptable to scientists. The observations together with the theoretical ideas and the inferences constitute the evidence for the existence of these submicroscopic entities or "things". But we are approaching the region of metaphysics. Just what status is to be allotted to perceptual and conceptual objects must be left to philosophers, for it is their business to discuss the nature of reality.

Laws of various kinds have been distinguished, but it will suit our purpose to confine ourselves to a consideration of

(1) Descriptive laws
(2) Quantitative laws.

Descriptive Laws. Man is an observant animal. From the earliest times he must have recognised "things" by their properties. Wood floats on water, and burns. Diamond is harder than anything else. Fermented liquors produce intoxication. The recognition that certain properties associated together constitute a kind of "thing", or class, which is thereby marked off from other kinds of "things", is the assertion of a seemingly invariable relation. It is the statement of a common-sense law, but such a conception is not usually called a law. It is too elementary and commonplace a notion to be dignified with such a name; and yet such common-sense laws are the foundations of science. They represent our first successful attempts to apprehend order in our environment, so that we can proceed with our efforts at its explanation or control. Because the properties of a kind of "thing", or some of these properties, stand in a seemingly invariable relation to one another, it will be possible to obtain universal agreement about them, and they are therefore the fitting subject-matter of science. It is a common-sense law to say that there is such a thing as gold, or "gold exists". This is so because it is found that certain properties, such as yellow colour, very high density and great malleability, are associated in certain objects. However much an object may resemble gold, and however much I may have paid for it, if the required properties are not all present together in it to the required degree, I shall be justified in my suspicion that it is not gold.

The same sort of laws constitute the foundation of the biological sciences. Strictly speaking, it is a law of biology to say that there are such things as horses, although no such statement appears in the written body of scientific doctrine. Nevertheless, this law is implicit in it. If asked to expand

the law as here stated, a scientist might say, "a certain class of animals exists, each member of which possesses certain qualities: other classes of animals possess some but not all of these qualities: because of the unvarying association of the qualities which have been detected in this group of animals, a class-name is to be given to them, to wit, horse." When the qualities have been enumerated, if carefully observed and judiciously selected, a beginning has been made at classification, which is the first step in reducing to order the vast mass of material which is treated by some of the branches of science, notably by zoology, botany and mineralogy. Chemistry has had to classify its material; so has astronomy. The stars can be classified by their positions, their brightness, sometimes by their colour, and in other ways. A separate law is not necessary to assert the existence of each separate thing which may be the subject-matter of science, because, although no two objects are identical in all their qualities, those which are alike in certain selected relevant qualities can usefully be grouped together, forming a kind, class, species or whatever the technical name for the group may be.

The laws which assert that there is a particular kind of thing, such as magnesium, or that there is a particular class of things, such as horses, are liable to pass unrecognised as laws by elementary students of science because they are not usually so labelled. The classificatory parts of science seem to be a mere preliminary ordering of the scientific material. What is commonly known as Boyle's Law is a quantitative law of physics, but Boyle's greatest contribution to science lay in his founding of modern chemistry. He was responsible for formulating clear ideas about the differences between elements, compounds and mixtures, an achievement which is of fundamental importance and made the development of chemistry possible. A basis of classification for chemical substances had been found, and, although not specified as such, several laws were implied in his definitions of the terms "element" and "compound"; for instance, "there are pure and impure substances", "there are pure

substances which cannot be decomposed", and "there are pure substances which can be decomposed". Boyle's contribution to chemistry might have been called the Laws of Pure Substances.

When these observed unvarying relations, which are taken to be invariable relations, are first consciously expressed in the form of laws, we have maxims or adages. Examples are, "when the North wind doth blow, we shall have snow", and "rain before seven, fine before eleven". These "laws" are the results of the common-sense observation of events, at rather a low level of accuracy it is true, but they are of a type about which universal agreement could have been obtained, if they had been correct statements of fact. When certain investigators, strongly imbued with the spirit of curiosity, began to institute much deeper and more searching inquiries than would ever have been made by the exercise of common sense alone, it was found that some of the relations asserted by these traditional maxims were not in fact unvarying, and the crude laws of common sense began to be doubted. Better approximations were substituted for them.

The generalizations of science are thought at the time of their formulation to be reasonably accurate expressions of certain invariable relations which are to be found in the outside world, but at first they are not looked upon as ultimate or unalterable. They are often put forward with the realisation that they are tentative and hypothetical. If further work supports a generalization and no contrary evidence is adduced, it may stand as a scientific law; but frequently such general statements are found to have a restricted application when fresh observations, which the law cannot cover, are made in the same field of inquiry. The law must then either be abandoned, or must be re-expressed to cover all the known cases, including those just discovered. An example of the development of a law from an insufficiently accurate original form is furnished by the history of the biological problem of reproduction. As a result of Harvey's physiological work, the dictum *ex ovo omnia* was at one time

the orthodox opinion about the mode of reproduction of animals. One hundred and fifty years later Linnaeus supported the famous maxim *omne vivum ex ovo*, in which the assertion is extended to include all living things. Later investigations showed this law to be untrue, and also led to the redefinition of the technical term "animal". Asexual reproduction by fission and by budding were discovered. The law of reproduction in its most comprehensive form now amounts to little more than a denial of the occurrence of spontaneous generation: *omne vivum a vivo*. Less general statements which refer to restricted classes of living things are current to-day.

The problem before scientists has been and still is that of deciding what are the invariable relations. As knowledge accumulates and more refined methods of observation are invented, a simple law which seemed to be satisfactory when first formulated is sometimes found to be inaccurate. It is typical of progress in science that new discoveries upset old laws. The original law is, so to speak, split into two or more others, which are more restricted in scope than the parent law. The loss in generality provides a gain in precision.

So far we have dealt only with such laws of unvarying associations as have led to the cataloguing of the subject-matter of science and its classification into conveniently ordered groups. There are also many laws which describe the behaviour of matter in certain reproducible conditions. Such a law is that of the behaviour of magnet poles: "Unlike poles attract, like poles repel one another." It is these laws of behaviour that lend themselves more particularly to quantitative treatment, but two questions arise and demand to be answered before we go on to consider the quantitative laws. First, what must be the attitude of the scientific worker to his material if he is to formulate laws successfully? Secondly, how does he know that the relations discovered are invariable; that is to say, why is there universal agreement?

The attitude of the scientist to his material is not essentially different from that of any conscientious craftsman. He must put on one side any prejudices or preformed views which he has acquired by reason of his upbringing or sur-

roundings. He must have no bias in his judgments of what relations are invariable. He must be on his guard against all subjective errors, and must be suspicious if his observations too often lead him to find what he expects. He must be detached and unemotional in his work. He must take nothing for granted, but must verify his observations and conclusions by the most stringent tests which he can devise. The outstanding characteristic of good scientific work is the extreme care with which it is done. All known sources of error must be taken into account, and allowed for if possible; only when such precautions have been taken are the observations regarded as the best available. Evidence is sifted with the utmost thoroughness before a conclusion is reached.

In ordinary affairs, for example in the administration of justice, there is often a pressing need that a decision should be reached at a certain time on the evidence available. The decision cannot be adjourned *sine die*. It is otherwise in science. Doubtful decisions are labelled as doubtful, or are disregarded. Unconfirmed observations are put on one side pending confirmation. Resumption of work is often postponed because it is realised that no more progress can be made until technical improvements in apparatus are forthcoming. Publication of results is frequently delayed until the worker has made out so good a case for his assertions that he can forestall any criticism that might reasonably be levelled against him. Premature publication is bad science, although the temptation may be very great when it is known that there are rivals in the field at work on the same problem.

There can be no universally applicable rules which, if faithfully carried out, can be guaranteed to ensure success in scientific discovery. Success will depend on individual acuity and alertness: and, of course, on whether there is anything observable to detect. Some men are born observers and have a flair for detecting the relevant. The most minute changes in an object, or differences between two objects, are seen by such men to have significance. The great founders

of zoology and botany were of this type. Sometimes a discovery attracts sufficient attention from other scientific workers or from the Press for its maker to be acclaimed as a person of great distinction. Equally valuable discoveries which fail to attract attention may go quite unheralded. The acute observation by Röntgen of the fogging of a photographic plate when near to an exhausted glass tube through which an electric discharge was passing, soon became known as the Röntgen effect. Later the effect was explained and incorporated in a rapidly expanding branch of physics. Many other "effects", named after their discoverers, are mentioned in text-books. It must be noticed that new observations are given the preliminary name of "effect" before they are understood, but the name is often dropped later because of its lack of descriptive power. In common parlance an effect presupposes a cause, and any new effect at once challenges scientists to search for the cause of the phenomenon, meaning that a search is made in detail to discover the condition or conditions in which the effect occurs. When it is concluded that an invariable relation has been found between two states of the system under consideration, it may be said that a scientific law has been discovered.

The second question with which we are concerned is essential for an estimate of the truth of science. How does the scientist know that he has discovered invariable relations? Why is he so sure that there are any invariable relations to be discovered? Why, to change the emphasis, is he certain that the relations are really invariable? The answer usually given is that the scientist knows that the relations in which he is interested are really invariable because he makes inductions or inductive inferences, but such inferences are by no means peculiar to science and must be examined. We must find out what they are worth.

It is often pointed out that the reasoning used in science is a combination of deduction and induction. This is so; but no other processes for drawing inferences are known. The deductive-inductive method is used in the conduct of

practical affairs and in abstract thinking. It is very necessary to draw inferences, which may turn out to be true but are sometimes false, in the practice of law, medicine, commerce and all kinds of administrative business. Those practitioners who are equipped with the best reasoning powers will on the whole make fewest mistakes, but although their processes of reasoning from available data are of the same kind as those used by scientists, the reasoning by which practical affairs are conducted is not as a rule subjected to the same careful scrutiny as that by which scientific conclusions are reached, nor are emotional factors necessarily excluded from influencing a decision, as they are in scientific work. The scientist must wait for further data if he cannot draw an incontrovertible conclusion, but the man of affairs must often act on whatever data are available.

Inference is any process by which we pass from one judgment to another. The two kinds of inference which are distinguished are deduction and induction. Deduction, which has for long been the happy hunting-ground of formal logicians, is the process of deriving a particular statement from a general statement, a less general from a more general, or one particular statement from another. Deduction does not add to the total of knowledge. The most it can do is to draw attention to a fact which was already implicit in previous knowledge. Thus the only novelty introduced by the process of deductive reasoning is psychological novelty. If the premisses are true the conclusion will be, but in deduction the conclusion is always contained in the premisses. Nevertheless, deduction is one of the processes by which we reason and have reasoned for centuries. The reasoner backs his opinion about a particular case by showing that it is an example of a general law. This man is bad-tempered, for he has red hair, and all red-haired men are bad-tempered.

The deductions used by Harvey in his argument to establish the fact of the circulation of the blood are the simplest common sense. If the heart is a pump and its supply of blood is cut off, it will become empty and lose colour; if its exit is blocked when the supply of blood is restored, it

will become blood-coloured and distended. Such deductions are examples of the ordinary operations of the human mind, not of the exercise of a special scientific intelligence. Deduction was fully investigated and systematized by Aristotle, and has been the corner-stone of logic ever since.

But deduction cannot function unless there is a supply of acceptable generalizations. These are plentiful, for we are most strongly prone to accept general statements and to argue from them, probably because to do so gives us the impression that we have thereby acquired certainty. We are uneasy and uncomfortable when we are uncertain, and, unless we are on our guard, are therefore the more willing to accept such statements without too careful an inquiry into their grounds. The process of arriving at general statements is called induction and, like deduction, is also a common mental process without which we cannot reason at all about science or any other subject. The difference between the inductions of the scientist and those of, say, the politician, is that the scientist collects as many relevant data as he can before making his inductions and excludes all emotional factors from them, thus ensuring that his knowledge has the highest degree of probability possible. He can afford to do this because his subject-matter is simpler as a rule than that of the man of affairs. His results are the more reliable in consequence.

Induction is the process of reasoning by which we pass from a judgment about observed situations to a judgment about all situations which are similar in certain respects. If I have encountered ten white cats all of which are judged to be afflicted with deafness, I may be tempted to pass to the judgment that all white cats are deaf. If by all, I mean "all, past, present and future", I am making an induction of the kind entertained by scientists.

Aristotle, who was a man of the greatest intellectual power, was quite aware that the truth of the conclusion of a syllogism depends upon the truth of its premisses. He therefore sought to show how the absolute certainty of general statements could be substantiated. On reflection, it is soon

obvious that there are two kinds of general statements which have the same verbal form, but which are not equally general in meaning. The first is arrived at by what is called complete enumeration. For instance, I can substantiate the claim that all my books are bound in cloth by inspecting each one of them in turn, and, if it is the case, by delivering as many separate judgments, "this book of mine is bound in cloth", as there are books in my possession. The statement of my claim could, perhaps, be called a general statement, but if so, it is a general statement of a special kind. It refers to a restricted class of objects all of which can be observed here and now, and can only be called general by courtesy. In such cases certainty can undoubtedly be obtained, but it is a certainty which is very limited and unproductive. Complete enumeration is the method of stocktaking: it is useful in its own sphere, but it is not what is meant by induction. The limitation of its usefulness occurs because in the vast majority of cases in which a generalisation is required, by the very nature of the case, enumeration cannot possibly be complete.

The second type of generalization is to be found in the assertions of science; for example, "the melting point of tin is 232° C". This statement, about as dull an utterance as can be made in the hearing of a non-scientist, is the expression of a general law. It means that there is a substance called tin, one of whose properties is that, other conditions being the same, all specimens of it which have existed in the past or will exist in the future, have had or will possess the property of melting at 232° C. The other properties of tin are not stated in this law. Other laws would have to be constructed in order to express them. The point is that we have complete confidence in this law of tin within the known limits of accuracy of our thermometers, although we may only have measured the melting point on a few occasions and certainly cannot measure it with regard to all specimens of tin, past, present and future. Complete enumeration is neither possible nor is it thought to be necessary, and yet we feel pretty certain about the truth of the law. We have found an invariable

relation: but how do we recognise it as invariable? That is the problem of induction.

We may say that inductive inference consists of a mental operation by which knowledge of one or more instances of a relation leads to a conviction that this relation will always be found, provided the circumstances of its original observation are repeated. Our reason for holding this conviction is that in the case of certain relations, well known to common sense and to science, it is found that experience bears out our expectations. Until we find an instance which is contrary to our induction we are entitled, on grounds of expediency, to call the induction true. But great care must be used in making inductions, for the degree of truth they possess is relative to the knowledge on which they are based. An induction is more or less probable, according to its nature and to the inclusion of as many relevant data as possible. Those who demand a proof of induction are asking us to extract certainty from ignorance. All we can in fact do is to extract probability from experience.

How did Aristotle attempt to establish the absolute validity of induction? He says that "in the order of nature, the general principle is prior to the sensible fact".[1] By sense experience we gain knowledge of particular facts and then, by some mysterious intuitive act which it is beyond the power of logic to assess, the intellect apprehends the general principle, which, so to speak, was already in existence and was waiting for a mind to grasp it. This latter process, called "induction" by Aristotle, involves us in an intuitive theory of truth, if we are to accept its findings without the application of any further tests, and the intuitive theory of truth can be criticised on the grounds that there is not necessarily any agreement between intuiting minds. Aristotle goes on to explain where we may look for reasons for accepting or rejecting these intuitions about our sense experiences, and calls the procedure "dialectic". Under this heading much of what he says has been incorporated in the voluminous writings of those logicians who have sought

[1] Joseph, H. W. B.: *An Introduction to Logic*, p. 382 (O.U.P.).

to expose the grounds of induction. Rules have been suggested for making inductions; and the methods which have been used by the most successful scientific thinkers in their work have been carefully scrutinised, but no solution of the problem of induction has been reached. No one can say just why certain inductions fit the facts of experience so well while others fail to do so.

All inductions are probabilities only. The man of science cannot be persuaded to say that his inductions are absolutely certain. He will not say that this day must inevitably be followed by night. He will admit that the whole of human history records an unbroken sequence of days and nights. He will be prepared to admit, in the terms of current speech, that the alternations of day and night are caused by the rotation of the earth upon its axis. He will be prepared, if pressed, to attempt to calculate the probability that this day will be followed by night and that the sun will rise to-morrow, but he will go no farther. Yet his conduct will be quite unaffected by the uncertainty which his calculation expresses. He will agree with common sense that this law of the succession of day and night is satisfactory for all practical purposes, but about absolute truth he is discreetly silent.

Attempts to solve the problem of induction have led to the enunciation of two principles which are often stated to be the fundamental intuitions on which science rests. They are called the *Law of the Uniformity of Nature* and the *Law of Universal Causation*, but it can be shown that the first is either untrue or is singularly ill-expressed, and that the second, although useful in medicine and meteorology, is unnecessary so far as pure science is concerned. These laws were made by logicians, not by scientists, which perhaps accounts for their grandiose titles. In what sense is nature uniform? Certainly not in the sense that the future resembles the past in detail, unless we subscribe to some unsupported doctrine of long-term recurring cycles, of one of which the whole of recorded history represents but a fragment. Nor do the objects of nature resemble one another in detail.

Recognisable differences can easily be detected even between "identical" twins. Nevertheless, it seems that things have behaved in much the same way over the period of human observation. There is no reliable evidence that the general pattern of natural events has changed since the earliest known times, and we have been justified so far, when making our day-to-day plans, in assuming that this general pattern is not in process of changing. Because certain relations have not been observed to vary over a relatively short period of time, we assume that the same relations held before we were able to observe them, and that they will continue to hold in the future. It is in this sense that the Law of the Uniformity of Nature is regarded by some writers as the fundamental induction. Progress in science has certainly depended upon our making the assumption that natural events do not occur capriciously. It seems that there are invariable relations to be discovered, as far as our experience goes; and, until these assumptions can be shown to be false, or until we are confronted with a situation in which no further progress can be made so long as these assumptions are maintained, we shall presumably continue to look for more of such relations. No strict proof of the Law of the Uniformity of Nature can be given.

The Law of Universal Causation means that similar causes always produce the same effects. No judgment of the probability of the truth of this statement can be made until we are quite clear what we mean by *cause*. We have to distinguish between the use of the word in common speech, as in the ordinary transactions of life, and any meaning which philosophers may assign to it.

It must be remembered that words were adopted by man for his own uses to express those ideas which seemed to him to be important. *Cause* is such a word. It is not a technical term in science. It is a name for a relation with which we are all familiar. If I will to do something and succeed in doing it, such as breaking a wooden stick in two, I can be said to have caused an event. I may perhaps place the stick across my bent knee and pull the two ends of the stick until

it breaks. What is the cause of the breaking of the stick? Clearly, if I had not willed the event it would not have occurred. But it may be said that the cause of the breaking of the stick was its brittleness. It is true, perhaps, that this was a necessary condition of my success. Or it may be said that the cause of the breaking of the stick was my exceptional bodily strength. This, perhaps, was another necessary condition. Or the particular arrangement of forces which I brought to bear on the stick may be cited as the cause of its breaking. Other necessary conditions, such as my possessing a stick, or knowing what procedure to adopt in order to break it, also exist, but these last two would not usually be called causes. One of the conditions preceding the breaking of the stick is selected and attention is focused upon it. The selected condition has relevance to some situation and is of psychological importance. It will be called *the* cause of the event, but because the selection of one condition among many may be a matter of personal preference, there is often a possibility of argument about causes, and there may be difficulty in deciding between the disputants.

In assigning a cause to a particular event there is more than the selection of some relevant condition which must be present if the event is to take place. The idea of time sequence is involved. The cause must *precede* the effect. The conditions or condition which constitute the cause must be arranged first, and then the change in the situation, or effect, will occur. If what is thought to be the relevant condition is found to be simultaneous with the effect it cannot be the cause; both phenomena must be the effect of some other cause or causes. In considering an event as a whole, we choose a cause and an effect from among the constituent parts of the situation, but the cause and the effect cannot be interchanged. The cause must come first if it is to be so called, because the notion of cause in objects outside ourselves is derived from our belief that we can cause events by translating our will into action, a process which occurs in time. We apply a force to the stick, and *then* it breaks. This common-sense meaning of cause is adopted by the sciences.

Search is made for the relevant conditions preceding the phenomena under investigation. We say, following J. S. Mill, that if an event A occurs when conditions *a*, *b*, *c*, are present together but not when conditions *b*, *c*, *d*, are present together, *a* may be a cause of A, but *b*, *c*, *d*, cannot be causes of A. In this way we arrive at causes for practical purposes. Arguments of this kind are the basis of the method used by scientists for identifying those conditions relevant to the occurrence of classes of events.

When we attempt a more detailed analysis of the causal relation, as philosophers do, in order to lay bare the connecting link or links between a cause and its effect, we at once find ourselves in the midst of controversy and dissension. How can one phenomenon be the cause of another? How can we picture a cause as having power to produce its effect? What is the link between them? What is meant by the necessity of an effect following upon a cause? There is no agreement about the answers that should be given to these questions, except, perhaps, that they cannot be satisfactorily answered. All we really know is the succession of events, antecedent and consequent. It is our experience that closely similar antecedents have similar consequents, and the relation that is assumed to exist between them is called the causal relation. That this relation often holds in nature, as far as we can tell by the observation of events, is summarised as a principle or law, sometimes called the Law of Universal Causation. This may be looked upon as the sum of all scientific laws, those discovered already and those yet to be discovered. Whether the law holds throughout nature, that is, whether it is rightly called universal, is unknown, but it has value to the scientist as a methodological assumption.

Quantitative Laws. The Royal Society of London for Promoting Natural Knowledge was granted a charter of incorporation by Charles II in the year 1662. Its members were united by a common impulse: that of curiosity about the happenings of nature. They were actuated by the very common desire to know why things are what they are and how they work. These men, like their forefathers, sought to

explain nature, and their efforts were soon to be crowned with striking success. A predecessor of theirs, the Italian Galileo, had developed a method of investigation which yielded the most interesting results. He had applied the common-sense notion of measurement, which was, of course, already freely in use in commerce and the constructional trades, to his experiments. Galileo took a stout plank and made a groove along it.[1] The groove was lined with vellum to make it as smooth as possible. One end of the plank was raised a few feet above the other and a smooth brass ball was allowed to roll down the whole length of the plank. The time taken by the ball to do so was measured by means of a water clock. The quantity of water which escaped from a small hole in a large vessel while the ball was travelling its course was obtained by weighing the water collected. The weight of water was taken as a measure of the time, and no considerable differences in time were found for a large number of experiments in which the plank was kept at a particular inclination and in which the ball travelled the whole length of the plank.

Galileo's next step was to perform a similar series of experiments in which the ball was allowed to traverse only one-quarter of the length of the plank. Numerous trials were again made, and the time taken by the ball to perform this shorter journey was one-half the time for the full distance. In a further series of experiments, the ball was made to traverse other fractions of the length of the plank, such as one-half, two-thirds, or three-quarters. Each set of experiments showed that the distance travelled by the ball was proportional to the square of the time of descent. Other sets of experiments were made with the plank at other angles of inclination to the ground. All the results revealed the same relation between distance and time, with only slight variations. Galileo had discovered a quantitative relation between distance travelled and time of descent which nowadays we should express algebraically thus: $D \propto T^2$, where

[1] See Sherwood Taylor, F., *Science Past and Present*, p. 82 (Heinemann).

D is distance and T is time. This is Galileo's Law of Falling Bodies, and it is a new kind of law. It differs from those we have considered above in two important particulars. First, it states that there is an invariable relation between the time taken for a body to fall and the distance through which it falls. This relation Galileo expressed quantitatively, thereby showing that it was unvarying. Secondly, the law is of a very general type. It applies to any falling body. Although he had experimented with only a few falling bodies, and these were not falling freely, but were constrained by the groove in the plank down which they rolled, he had sufficient insight to realise that his law would apply to all falling bodies, provided that no conditions were introduced which favoured one body rather than another. He said, in effect, that the type of substance used is immaterial, as is the amount of matter in it, but that the act of falling can be expressed by a numerical law, whatever the body under consideration may be.

Certain features of Galileo's experiments were so fruitful for the discovery of quantitative laws that they fixed the procedure from his time to our own. They may be summarised thus:

(1) He isolated a phenomenon in such a way as to eliminate disturbing factors.
(2) He made such dispositions of his apparatus as to allow him to make measurements of reasonable accuracy.
(3) He repeated his experiments again and again to ensure the correctness of his measurements.
(4) He varied one measurable property of his system at his pleasure and observed the accompanying change which took place in another measurable property.
(5) He applied mathematical reasoning to his measurements, thereby showing that an unvarying relation existed within the range of his observations, and expressed this relation as a quantitative law.

Galileo must have realised the general nature of the problem he was investigating. Although the motion of the

ball is modified and slowed down by the constraining effect of the groove, it undergoes a kind of fall. He understood that there was no essential difference between a body falling freely and a body rolling down his specially prepared plank, so far as the relation between time and distance was concerned. The history of physics shows that he was right in his assumption, the making of which marks him as a man who had an exceptionally keen understanding of physical processes.

We may now return to the early days of the Royal Society and the establishment of another famous quantitative law. It was in order to settle a controversy with an opponent, who had criticised his explanation of the fact that mercury stands at a height of about twenty-nine inches in a barometer, that Robert Boyle, one of the founders of the Royal Society, undertook the experiments which led to the discovery of the law with which his name is still associated.[1]

Boyle took a long glass tube and bent it near one end into the form of a letter J. The shorter limb was sealed at the end. The two limbs of the tube were then graduated by pasting a paper scale along them, the scale being divided into inches and eighths of an inch. A little mercury was poured into the tube, so that it stood at the same level on either side of the bend of the J. The effect of this was that a certain volume of air had been trapped in the shorter limb, whose volume was measurable in terms of the paper scale pasted on the tube, and whose pressure was equal to that of the atmosphere. Boyle now added mercury to the longer open limb of the J-tube until the volume of the air in the shorter limb was reduced to one-half of its original value. He found that the mercury in the longer limb now stood at a height of twenty-nine inches above the mercury in the shorter limb. He had halved the volume of a quantity of air by applying a pressure equal to twice that of the atmosphere.

To anyone versed in the scientific method, as Boyle was, it must have been obvious that this observation might be

[1] See Hart, I. B., *Makers of Science*, p. 186 (O.U.P.).

an instance of a general law. It was necessary to vary the circumstances in order to draw a conclusion of a general nature. Boyle accordingly measured the volumes which the imprisoned air took up when different amounts of mercury were poured into the longer limb of his J-tube. He used pressures greater than that of the atmosphere and noted the corresponding volumes.

In order to find the relation between pressure and volume at pressures less than atmospheric, a different arrangement was necessary. He used a tube about six feet long, closed at the lower end, as a mercury reservoir. Into this he inserted a narrow tube, previously warmed to expand the air in it, which was open at the bottom but closed at the top with wax. When the air in this tube cooled it contracted, and, on raising the narrow tube, the air in it expanded, so that the mercury column stood at a level above that of the reservoir. The difference in these levels gave the excess of the atmospheric pressure over that of the air in his narrow tube.

In this way Boyle was able to take a series of readings of the volumes which the imprisoned air took up when subjected to different pressures. Measurements of the lengths of his mercury columns served to measure the pressures, which varied from a little over one inch up to nearly ten feet. He constructed a table in which his observed pressures were compared with those calculated on the assumption that the volumes of air are reciprocally proportional to the pressures. His results were quite good enough to convince him and others that he had found an unvarying relation, although his numerical results were not quite precise. Boyle's Law is expressed algebraically in the forms $P \propto \frac{1}{V}$, or $P \times V$ is constant.

It will be seen that Boyle employed the same method that Galileo used in order to establish a quantitative law. He confined a quantity of air in his apparatus, which was arranged so that two of the properties of the air in his tubes could be measured. He varied one of the properties at his will and found to what extent the other property was

altered. He made many observations with his apparatus, and, applying mathematical reasoning, he showed that, to a fair degree of accuracy, his observations were cases of a general law.

In Boyle's time the generality of this law was not fully recognised because the nature of air was not understood; but later it became known that there are many different gases, two of which make up ninety-nine per cent of the air, and that Boyle's Law applies to all of them. Like Galileo's Law of Falling Bodies, Boyle's Law is a numerical law; and is approximately true for all gases at temperatures well above the boiling point of the substance, provided that its chemical integrity is preserved.

These two laws and a few others are the foundation stones upon which experimental physics is built. For instance, the establishment of Galileo's Law made great advances possible in the branch of physics which is called mechanics, and an understanding of Boyle's Law has contributed very largely to the explanation of the behaviour of gases. Boyle's Law has also proved to be of the greatest practical use in improving the steam and other expansion engines.

It must not be thought that scientists are content with such an approximate generalisation as that of Boyle. The way in which science has developed has been by constant dissatisfaction with the results obtained by previous workers. All results must be checked. All measurements must be repeated, if possible with greater accuracy than before. Nothing may be taken on trust. If I claim to have established a law, others will test my conclusions before my law can become part of scientific doctrine. It is this sceptical attitude which enables us to arrive finally at laws to which it is possible to compel universal assent. The laws of science are not a matter of faith: they need not be accepted on authority alone: they are of such a kind that anyone, who is prepared to take the trouble and has the required degree of skill and understanding of the problem at issue, would be able to verify them for himself. In this way alone can universal agreement be obtained.

It has been stated above that Boyle's Law is only a first approximation. The crude statement of it just given requires modification before it can be said to state an invariable relation at all accurately. Extended observation and more refined measurement have shown that Boyle's Law must be split into several other laws: one for instance for use at high pressures and another for use when the gas is at such a temperature and pressure that some of it has already condensed to form a liquid. Such refinements of a law may be difficult to find. The expression of them in mathematical language may necessitate a knowledge of mathematics which is outside the intellectual equipment of the non-mathematician. But the purpose of the scientist in formulating such laws is clear. It is the discovery, in more and more exact terms, of invariable relations between observed quantities.

Some remarks have been made above about cause, and it should be noticed that these quantitative laws are in no way concerned with causes. Galileo did not succeed in finding out why bodies fall to the earth, but how they do. That they do fall is an experience common to everybody, and it would undoubtedly be psychologically satisfying if we could say why they do so. But the results achieved so far, by science seem to show that explanation is only more detailed description of what happens, the psychological satisfaction being greater the more familiar the terms in which such description is expressed. Desire for explanation is probably the underlying reason for much disinterested devotion to science and will be discussed more fully in a later section. Boyle may have started out to explain why a compressed gas acts on a piston like a spring, but he did not in fact give a very plausible answer to it. He answered the question, How? And so it is with all scientific laws. They are more or less accurate statements about selected portions of experience, but no causes are to be found. The cause of gravitation is unknown. It is, however, known that bodies gravitate, and, thanks to Newton, how they gravitate. It is known that the sun warms us and that energy transformations occur. But it is not known why they occur. Nevertheless the

notion of cause is useful, even in scientific discussion. It is a shorthand symbol, often saving many words, and so long as it is understood to have this symbolic function and nothing more, there can be no objection to its use. As has been said above, cause is, in fact, a metaphor taken from the universe of discourse to which the conception of will properly belongs. When I translate my will into action I can properly be said to cause an effect, but we have no knowledge of will in science. It is outside our sphere of interest because it is not at present susceptible to our methods of investigation. Cause, from the point of view of the scientist, is a useful symbolic fiction in so far as it is part of his ordinary common-sense equipment of expression, but it is not a technical term in science. When the term is used its metaphorical nature should be remembered.

If it is asked how these quantitative laws can be arrived at, it will only be possible to answer in very general terms. Some few of them may have been stumbled upon by a lucky investigator without any particular effort on his part, but such cases are rare in the history of science, and especially so in the domain of quantitative law. Most of them have been the result of careful and patient experimental investigation, aided by insight, but often hindered by unforeseen practical difficulties. Although it is the aim of an investigator to express invariable relations by means of laws, he does not know in advance what form the law will take. There is a limited number of mathematical formulae by which these relations can usefully be expressed, and it is often difficult, without aid, to see the law in the recorded measurements, unless it is very simple. The solution of this problem has been much facilitated by the application of a mathematical method invented by Descartes. The results of a set of experiments are expressed in the form of a graph, and by inspection of the shape of the curve so produced, the investigator is sometimes able to see what kind of law will probably express the relation he is concerned with. It is a method of trial and error, aided by insight and a knowledge of mathematics. The scientist, if he is a good one, will not

rest until he is as certain as it is possible to be, with the data and measuring instruments available, that his observed results are in accordance with whose which he can calculate by the use of his law. Only then is he in a position to publish his results, in the hope, perhaps, that his law may be accepted as part of the body of scientific doctrine. Results which will withstand the fire of criticism can only be obtained by one who is prepared to go where the facts lead him. He must not anticipate results but must wait until his work has earned them. The successful framer of quantitative laws must have both scientific insight and the good fortune to conceive problems which are capable of quantitative solution, but above all he must have intellectual honesty and perseverance.

The American novelist, Sinclair Lewis, has a passage in his novel *Martin Arrowsmith* which describes some of the qualities necessary for the framing of quantitative scientific laws. It is written in vigorous, emotive prose: "He (Martin) then prayed the prayer of the scientist: God give me unclouded eyes and freedom from haste. God give me a quiet and relentless anger against all pretence and all pretentious work and all work left slack and unfinished. God give me a restlessness whereby I may neither sleep nor accept praise till my observed results equal my calculated results or in pious glee I discover and assault my error. God give me strength not to trust to God.'"

The Attempt to Understand and Explain the Phenomena under Review

Scientific Theories. It has already been said that the method by which science proceeds is the construction of laws which state that invariable relations exist between the properties of things, and that some of the most important of these laws express quantitative relations. But knowledge of the laws does not serve to explain the occurrences of nature at all fully. Something more is required. Let us see what is meant by explanation. Successful explanation is the expression of the unfamiliar in terms of the more familiar. A

mystery is explained when it is cleared up, that is to say, when a more detailed account of the event has been given. Some of the ancients explained the apparent fixity of the earth in space by saying that it rested on an elephant, which in turn was supported by a tortoise. This may perhaps have been a poetic conceit, but it contains an element of all explanation, namely that of translating unfamiliar or mysterious events into terms of those which are more familiar. The idea that a heavy body could be poised in space seemed unnatural and mysterious, whereas, a heavy body was known to be capable of support by a strong creature like an elephant, and the arched shell of a tortoise was also known to be able to support a great weight without being crushed. The explanation offered drew attention to cases already known in which great weights could be supported and hence it diminished or removed the original mystery. The explanation was a theory of cosmic structure.

So many explanations of things that have mystified man are known in the history of ideas that it is quite unnecessary to mention more than one or two by way of illustration. In the cruder anthropomorphic religions the pantheon contained beings which were explained to the devotees of the religion as being like men, except perhaps that they had the heads of birds or bulls, or possibly they had wings or tails. These fictitious beings were also usually said to have human powers, virtues or vices, in an accentuated degree. Such descriptions were, in a sense, theories, for they attempted to explain the nature of the unknown and mysterious in terms of the mundane and known. Myth and theory are very closely allied.

There is another element to be found in the explanations offered in ordinary life. An explanation is frequently acceptable if an occurrence can be shown to be an example of a general law. We are somehow satisfied if we can bring ourselves to believe that an event which in our experience is unique or mysterious, is in some respects not unique, but is a member of a known class of events. Suppose I notice that an electric light bulb which has been in use for some time

has become blackened inside, but am at a loss to understand why it should be so. I am at once satisfied if I am told that my observation is a particular instance of the very well known general law that solids which are heated to temperatures not far removed from their melting-points usually give off appreciable amounts of vapour and that the filament of my electric light bulb was such a solid. The explanation, perhaps, is news to me. I have never heard of the general law before. But because the event I have witnessed has been shown to be a particular instance of a general law, my curiosity is allayed. I have received an explanation.

It seems then that there may be two elements in explanation. Either the event may be translated into terms which are more familiar and therefore better understood, or it may be shown to be an example of the operation of a general principle, there being a tendency to accept such principles without further question. Either or both of these elements may be present in an explanation of the kind given in ordinary life and either of them serves the purpose of explanation if it removes the mental uneasiness which caused an explanation to be sought. Are both elements present in scientific explanation? At first sight it would appear to be so. Scientific laws are sometimes said to explain experience. Very often a number of separate physical laws which hitherto had seemed to hear no relation to one another are shown to be cases of a more general law. We proceed from a law of restricted scope to one of greater generality. The inverse square law of attraction, together with the laws of motion, explained the behaviour of falling bodies on the earth's surface, the tides, the orbit of the moon, the orbits of the planets, and other things as well. The laws for the separate systems were shown by Newton to be cases of a more general law, the Law of Universal Gravitation. He proceeded from the laws of separate systems to a law of the greatest possible generality, but however great our admiration for Newton's achievement may be, we are still psychologically unsatisfied. What we should like would be an answer to the question "What is gravitation?" or "What is

gravitation like?" or even "What is actually happening when one body pulls another towards itself?" But the Law of Universal Gravitation provides no answer to these questions; nor was it intended to. It was intended to summarise our inferences from observations of certain very extensive regions of nature, but although it serves the purpose for which it was constructed with the greatest success, it quite fails to explain gravitation. And yet it is the aim of science to still the curiosity of man by explaining events in the outside world, an end which the inclusion of a number of laws in a more general law does not succeed in attaining. Such greater generalisation is certainly a step towards explanation, but the very thing we want most to know is left unsaid. There is some satisfaction to be derived from generalization, but we do not feel that it is maximum satisfaction.

It is suggested that those explanations of events which have been deemed to be successful have been made by the use of analogy. A hypothetical picture of the observed but unexplained event is given in terms of some event with which we are already familiar; and it is the familiarity which is so satisfying and which leads us to accept the explanation. Mental constructions made with the intention of explaining laws are called theories. By way of example, let us consider the theory which is intended to explain the laws of light. We have no direct knowledge of the transmission of light. Our sensations are of coloured surfaces which may be more or less dazzling. If one such dazzling coloured surface is present in our vicinity we are frequently able to see a number of other coloured surfaces as well, but in the absence of the dazzling coloured surface we can, perhaps, see nothing. All we know is that there is a relation, which we call visibility, between the two coloured surfaces. From these sensations of coloured surfaces the inference is made that there is something, called light, which passes through space from the coloured surface to which our attention is turned to the eye. But what passes? What is it like, and what does it pass through? Newton favoured the suggestion that minute particles or corpuscles, like those with which we are familiar

in a cloud of dust but very much smaller, are shot off by the luminous body and strike the retina, or sensitive inner surface of the eye. This is a theory of the transmission of light. Newton had not observed any such light particles or corpuscles, but his suggestion serves to explain the observed facts in terms which are to some extent familiar. Moving particles are familiar objects of common sense. Bullets move in approximately straight lines: a ball thrown obliquely at a hard surface bounces off so that the angle of incidence is very nearly equal to the angle of reflection. The laws of the behaviour of light are like those of moving, but very much larger, particles. The theory has the necessary merits of accounting for some of the laws of the transmission of light and also of satisfying the inquiring mind. It has an additional merit in that it does not postulate any medium through which the particles or corpuscles are transmitted. We can easily imagine a bullet passing through empty space.

Nevertheless, the particle theory is not the only possible theory. The great Dutch physicist, Huygens,[1] and, more vaguely, Robert Hooke in England, had suggested a different analogy, for there are other ways of getting from place to place than by being shot out of a gun: surf-riders are brought to the shore on the crest of a wave. Perhaps the idea of moving waves will provide the required analogy. If a stone is dropped into still water, waves can be seen to radiate from the centre of disturbance: they move outwards in circles. In a similar way, said these men, light waves might move outwards in concentric spheres from a luminous point. Just as the particle theory attempts to express the unknown in terms of the known, so this theory describes a mysterious phenomenon in terms of something which is more familiar, but of the two the wave theory was for a time much more successful in explaining the laws of light and seems on the whole to have had greater psychological appeal. Physicists have preferred it to the particle theory in spite of the

[1] Christian Huygens (1629–95) completed much of Galileo's work, Robert Hooke (1635–1703) became Secretary of the Royal Society in 1678.

awkward conception of waves which move in empty space. Waves, to the common-sense way of thinking, are due to the relative movements of different parts of some medium: there must be something which undulates. Strenuous attempts have been made to obtain clear evidence for the existence of such a light-bearing medium, but the search has led physicists into deep waters. As long ago as 1933 Lenard wrote, "Originally, in Huygens' case, the ether appeared as the medium in which the waves of light are propagated, the knowledge of which was very greatly extended by Young, Fraunhofer and Fresnel. Then, thanks to Faraday, Maxwell and Hertz it was generally recognised as the medium of all electro-magnetic forces, which are also the essential feature of light-waves. Later on, the interference experiment continually refined since the time of Fresnel, together with observations of double stars, showed that the ether cannot be assumed to be either stationary or in motion in the whole of cosmics space, but that it—as the medium in which light and all electro-magnetic fields are propagated with the velocity of light—shares to a corresponding degree the motion of every heavenly body, such as the earth, and indeed of every atom of matter to which it is in close proximity."[1] It is clear that the question of the ether, being bound up with those of the nature of space and energy, is full of difficulties which have not yet been more than partially resolved.

It has been mentioned in passing that it was possible to deduce some of the laws of the transmission of light from Newton's corpuscular theory. Had it not been possible to do so, the theory would never have gained credence. In fact, if a theory is to be accepted it is necessary both that the known laws of the section of physics to which the theory belongs should be capable of being deduced from it, and also that it should be possible to predict new laws, either from the theory as it stands, or from a slightly modified and extended form of it. In this sense, a theory must be fertile as well as psychologically satisfying. The triumph of the wave theory of light came about because more of the laws

[1] Lenard, P.: *Great Men of Science*, p. 379 (G. Bell & Sons).

of light could be deduced from it than from the corpuscular theory, but the wave theory is being much modified by advanced physicists to-day, because of its own failure in the light of recent research.

Sometimes, in order to decide between two theories, it is possible to suggest and to carry out a crucial experiment. The power of the rival theories to predict new laws is used to decide between them. A good instance is provided by the rival theories of the propagation of light which were supported by Newton and by Hooke. It was deduced from Newton's theory that light would travel faster in water than in a vacuum, but Hooke's wave theory led to the conclusion that light would travel faster in a vacuum than in water. Until these deductions had been tested, there was not so very much to choose between the two theories, and both had their adherents, for at that time there was no known way of measuring the velocity of light in water. In 1862 the crucial experiment was performed,[1] and the controversy was decided in favour of the wave theory, but as we have seen, the decision only meant that the edition of the wave theory that was then current was better than the contemporary corpuscular theory, not that it was final. The latest theory, which is at present in process of construction, shows signs of a return to the emission hypothesis.

Here is one more example. There is a theory that gases are made up of very small particles of matter called molecules and that these molecules are in indiscriminate rectilinear motion through empty space. As the molecules cannot be directly observed, there need be no universal agreement about this theory, although it is very widely held. If I like I can hold the theory that gases are made up of a continuous jelly, but I may have difficulty in deducing the known gas laws from my theory, and it is quite likely that nobody else will adopt it.

We are now in a position to sum up the characteristics of scientific theories and to say in what manner they differ from laws:

[1] By Léon Foucault, Member of the Paris Academy.

(1) A theory explains a law or set of laws in the sense that the events which the laws are about are described in more familiar terms. A theory involves an analogy, whereas a law is a statement of an invariable relation and is founded on observation. A theory is sometimes expressible with accuracy only in mathematical symbols.

(2) A theory must be of such a kind that the laws which it claims to explain can be deduced from it. It is usually capable, perhaps with slight modification, of leading to the prediction of new laws.

(3) Theories are imaginative constructions or abstractions. They are systems of ideas about how things may happen, or what things may be like, for the details of natural processes are often inaccessible to direct observation. Theories always contain an element of conjecture.

(4) There is nothing in the nature of a theory which is able to compel universal agreement to it, although some theories are both plausible and widely accepted. Each scientific worker can have his own theories if he likes, but it is the theories of a few great men of science that have contributed the main body of scientific orthodoxy.

Thus science seeks to bring about "the reconciliation with our intellectual desires of the perceptions forced upon us by the external world of nature".[1] To this end scientists have found that it is profitable to adopt the common-sense principle of generalizing from experience. These generalizations, which are called laws, assert the existence of invariable relations between the properties of things, and the relations are of such a kind that universal agreement about them can be obtained. Further advances are made when the invariable relations can be shown to be quantitative. The laws are acceptable to scientific inquirers because they show the existence of order in a great number and variety of phenomena. Some of the great scientific investigators, by an act of imagination, have been successful in explaining certain laws or groups of laws by means of theories. These are acceptable, if fanciful, mental pictures of some of the obscure

[1] Campbell, N. R.: *What is Science*, p. 80 (Methuen).

facts of experience in terms of familiar experience. Some theories are adequate for their purpose and are satisfying to scientists, but there is nothing in their nature which is capable of compelling universal assent to them.

There is no suggestion that the laws of science which are accepted at the present time are final, or that to-day's theories cannot be improved. Science progresses by increasing the accuracy of its laws and by improving its theories.

CHAPTER II

SCIENTISTS AND THEIR WRITINGS

IT IS nowadays possible, if it is thought worth while, to make a machine to carry out many of the tasks, skilled or unskilled, which were once the peculiar province of human labour. External stimuli can be made to control a machine in much the same way as these seem to affect the human organism. Without employing more than a small fraction of the population, enough food, shelter and clothing can be produced for the needs of all. Another small fraction of the population can be used, if desired, to manufacture a private motor carriage for each person. We can look into the interior of a human body or into the depths of space; we can fly up into the air or dive to the bottom of the sea; problems of transport and communication have been partially solved; so has the problem of television; and the catalogue of technical achievements could be greatly prolonged. It is true that human beings have not yet learned to behave themselves very well, but their conduct is not within the province of science, whereas the situation outlined above is directly attributable to this. It is the scientists who have changed the face of nature by their control of it, a revolution which has been mainly brought about in the last three hundred years.

The scientists fall naturally into three classes, according to their functions, although these functions may overlap one another in the same person, and the life of any particular scientist may be diluted largely with a non-scientific way of living. To some men science is a mere hobby; to others it is an absorbing passion. To some it is the means of earning a livelihood; to others it is a stepping-stone in a non-scientific career; but leaving on one side those who have been

trained in science but whose interest in it is transitory or defunct, there is a large number of persons whose main working interest lies in some branch of science and who would naturally describe themselves and would be described by others as scientists. They are of three kinds: pure scientists, applied scientists, and teachers of science. The chief overlap of function is with the pure scientists and the teachers of science, as many University posts are given to those men who have contributed, or who show promise of contributing, to scientific doctrine, on the understanding that they will divide their time between further attempts at solving purely scientific problems and the teaching of students. There is also an overlap between pure and applied scientists, for an investigator with no other motive than curiosity has sometimes made a discovery while engaged on work having no immediate practical purpose, the application of which to a practical problem he has understood and exploited. It is not intended to argue that this division of functions is sharp, but that it is expedient to make it for the purpose of assessing the contribution which all those who can reasonably be called scientists can and do make to the life of the community.

Pure Scientists. Man finds himself beset with many problems: some he must solve if he is to survive; others interest him profoundly but are of no immediate practical importance. Problems of the second kind lead to speculative thought. If they are about being and knowing in the abstract, the result of this thinking is called metaphysics. If the problems are about concrete things and their relations, his speculations may give rise to science. It seems certain that the original motive for scientific thought was far removed from the sphere of practical living. It was strictly for intellectual satisfaction, the desire for which first arose among the classical Greeks. Ritchie says, "the idea of starting with a small number of elementary general propositions which are assumed and are explicitly not proved, and then proving everything else from them by strict logical reasoning, this is the special Greek invention. It is really

remarkable that such a method should ever have been devised and used by anybody, because it runs counter to all the dearest prejudices of mankind."[1] Thus the approach of the classical Greeks was intellectual, and except for Archimedes, who was something of an inventor, they did not go in very much for experimental verification of their speculations, and so, until the rigid testing of all hypotheses became the rule, progress was slow and sporadic. The primary aim of the pure scientist is to *know*, in contrast to that of the man who wishes to apply scientific knowledge to practical affairs. His aim is to *do*. The mere collection of facts about nature, or even the framing of quantitative laws, is not the highest achievement of which the scientist is capable. There have arisen from time to time certain great men, who were not only well acquainted with the known facts of the branch of science in which they were interested and who made their own contributions to it, but who have also possessed a penetrating quality of mind, or insight, which enabled them to see clearly the existence of relations in large tracts of experience where others either saw no relations or saw them but dimly. These men had the power of unifying experience and at the same time of simplifying it. They possessed, in some measure, the creative faculty, in that they saw some part of the pattern of nature so clearly that they were able to communicate their vision to others and to convince them of its value. Such men will live as the founders of the great scientific theories. Their greatness in human history is comparable with that of the great philosophers, poets, painters and composers of music, in that they had creative minds, each unique in its own sphere, each pre-eminent in his own time. Such were Copernicus with the heliocentric theory; Newton with the law of universal gravitation; Dalton with the atomic theory of matter; Darwin with the theory of natural selection; Clerk-Maxwell with the electro-magnetic theory of light; Planck with the quantum theory of radiation; Einstein with the relativity theory; these men had minds of unrivalled quality, and have permanently enriched human

[1] Ritchie, A. D.: *Scientific Method*, p. 3 (Kegan Paul).

thought. They and some others are the great interpreters and illuminators of nature. In justice it must be added that the above list is not complete, and that there have also been a host of workers of lesser intellectual stature who have contributed their quota to the picture of nature which we now possess.

The results of the work of the pure scientist are made accessible to all. Original work is usually first published in the journals of one or other of various scientific societies, thus informing those who are interested that new work has been done and submitting it to their judgment. Sometimes new work has first been disclosed in papers read before learned societies. There is no question of secrecy. The attitude is one of open co-operation. Important publications have often contained the solution to a problem which has been the concern of many investigators for years, and, although the great theories of science are sometimes attributed to one man, there is usually a sense in which such advances must be regarded as the outcome of the joint efforts of a number of men. Pure science is a collective achievement which transcends race or nation.

If it is granted that these great explanatory generalizations are the highest achievement of science, it is clear that classificatory and quantitative laws are the essential framework on which the edifice of science is built. The aim of the pure scientist is not so much to find out the true facts about nature as to create a comprehensive vision of it. The only way to do this in a manner satisfactory to scientists is to establish the facts and to discover true laws. Truth is a means rather than an end. If error is not excluded by the way, the goal cannot be reached. How remote that goal may be cannot be said at present, for although much has been done, there are still many baffling problems to be solved. Each new contribution must be found a place. The discoveries of to-morrow must be made to fit in with what we know already. Pure science is not the concern of a generation or two, or even of a few centuries. It is seemingly an endless quest.

Applied Scientists. The practical application of some scientific discoveries to the affairs of ordinary life is obvious enough to scientists and to laymen alike. Perhaps the discovery fills a long-felt want. No special training or insight is necessary to turn the new idea to account. The discovery of the first synthetic dye by Perkin and of X-rays by Röntgen are of this type. Very frequently the practical application is made by the pure scientist who first made the discovery and is worked out in some detail by him before he hands it over to the technician and manufacturer. There have been occasions when pure scientists have been asked to attempt to solve practical problems, as in the case of Davy, whose invention of the miner's safety lamp was in answer to a pressing need, and of Pasteur, whose solutions of the practical problems of silk-worm disease and hydrophobia allayed respectively an economic and a human scourge. Other workers, although mentally equipped for a life of pure science, have found time to concentrate on practical problems: such men were Kelvin, who solved many marine problems, and Koch, the father of medical bacteriology. Some others who have set out especially to solve practical problems are not notable for their achievements in pure science, although their inventions may have opened the way for great advances in it as well as in technology. Examples of workers of this type were Marconi, with his uncanny insight into the behaviour of electric waves, and Gaede, who set out to improve vacuum pumps and succeeded in showing the way to the modern solution of the problem of obtaining high vacua.

The motive for the work of the applied scientist is usually the natural human impulse to solve whatever problems are set before him. He is neither unduly acquisitive nor inquisitive, but because of the special knowledge which he has acquired during his training, he feels himself to be confronted with tasks which challenge his ingenuity and may well be within his powers. He seldom becomes rich, for as a rule he has not the qualities required for the acquisition of wealth. His interests lie in the ideas of science and the technique of the medium in which he works. He has something

of the craftsman in his make-up and enjoys the manipulation of his material. If in addition to these qualities he is found to be capable of organising the work of others, or shows a liking for the details of administration, or is found to have financial ability, he may go over to the business side of his firm, where he will probably make more money, but will cease to be a working scientist. There is no special merit in devoting the whole of a lifetime to a single kind of activity. We do what seems to be suited to our talents. A good many of the most successful of the technical scientists find themselves called upon to run research laboratories and to direct the work of others. It is to these industrial scientists, constantly spurred on to further efforts by their employers, that the great development of scientific appliances of all kinds is due. Very good scientific brains indeed can be had for a few hundred pounds a year.

Teachers of Science. The very intelligent teach themselves, for high intelligence is the quick apprehension of a situation either in the material sphere or in the realm of ideas. The teacher's task is light if the pupil has great ability and is keen to learn. But so great is the demand for scientific training that a large number of teachers is required who are capable of simplifying scientific situations and of presenting them in an easily acceptable form to a variety of students of very different mental powers. University teachers, many of whom have contributed to the literature of pure science and continue to contribute to it throughout their careers, are often glad to have the opportunity of teaching, as there is no better way of ensuring the mastery of a subject than to have to teach it. The need for giving a complete and relatively simple presentation of a problem focuses attention on it from a different point of view and often leads to a realisation of the significance of factors which had been missed before. Many great teachers have taken advantage of the fact that teaching can be an aid to research.

In schools the ideas to be taught are comparatively simple, for the minds of young pupils are less well furnished than those of their elders, and their co-operation is less sustained.

It is therefore necessary that the teacher should present his subject not only sufficiently attractively to hold the attention, but also in such a way that a pupil of moderate intelligence will be constrained, at the end of a lecture, to draw for himself the very conclusion to which the teacher's argument is directed. This is the ideal and, when it occurs, it is most satisfying both for the teacher and the taught; but much of the time of the teacher of science is spent in the didactic presentation of facts, for although the facts can easily, and sometimes more accurately, be obtained from books, the average pupil is reluctant to put what he regards as an unreasonable burden on his limited powers of application.

Teachers of science are confronted with two distinct problems. The first is the presentation of scientific ideas and the statement of the evidence regarding them. This is the purely intellectual side of science teaching and requires a good knowledge of the subject coupled with skill in exposition. The manual or manipulative side of science teaching is very different. It is necessary for the teacher to possess skill in handling the apparatus and the materials of his branch of science. A certain delicacy and deftness of touch are necessary, together with much forethought and patience. No demonstration should ever be allowed to fail, for if it does, the point it is intended to drive home will be lost in the impish glee of the young or the mild contempt which the more sophisticated reserve for the pretentious. It is a safe general rule that it will always repay a demonstrator to carry out a trial of his lecture experiments before the class is assembled, unless he is certain that he can get the intended result. In addition to the ability to give lecture-demonstrations, the teacher of science must possess manipulative skill so that the pupil can copy his movements. The experience of generations of laboratory workers has led to definite successful ways of carrying out certain operations, and this accumulated lore should be put at the disposal of students.

The teacher of science is an important if relatively unhonoured member of the community for three reasons. First, he is capable of smoothing the path and economising the

effort of the pure scientist during the period of his early training. The stimulus which an inspiring teacher can give may well decide the choice of a career. Secondly, in an industrial country it is evident that a large number of technicians who have had scientific training is necessary for the prosperity of the community. The better the quality of the teachers who are responsible for giving this training in applied science, the better for industry. It is essential that there should be sufficient teachers of this kind lest the quality of their work should suffer. Thirdly, the impact upon affairs of scientific discovery and thought is so evident to-day that every citizen should be familiar with an outline of scientific achievement and of its possibilities. An objective, if simplified, version of natural phenomena and, particularly, the sort of events that can happen, should be known to all members of an educated modern state. Apart from the sheer delight which is to be derived from knowing and the fascination of seeing, it is most desirable that those who have any say in controlling the lives of others should be well versed in knowledge of that which is the environment of all. Even if your painters, musicians and public entertainers can be allowed to omit, say, the quantum theory, from their educational curriculum, it is essential that the legislators and intellectuals should understand something of the power of electricity and of the properties of raw materials.

Scientific Writing. The chief medium of scientific expression is the writing of books and papers. Original contributions to knowledge are usually recorded in the form of papers sent to the journals of scientific societies. The body of knowledge thus accumulated is explained to students in the various text-books which are written, as a rule, by teachers of science, or, if the subject is applied science, by members of the research departments of the large manufacturing firms. All this writing is of a special kind. Ornament is dispensed with. The colourful phrase is excluded. Accuracy and clarity of presentation are regarded as of more importance than elegance or grace. Meaning must be quite unambiguous in spite of the necessity of conveying new and often difficult

ideas; these are sometimes best expressed in the symbolism of mathematics. Lawyers have attempted to achieve exactness of meaning by the use of technical terms which have a strict assigned meaning in law; and by the omission of punctuation. These devices make legal documents difficult for anyone who is not trained in the law to read and, incidentally, serve to ensure a demand for the services of lawyers. Scientists use plain unadorned prose in their writings, define their technical terms very carefully, and use symbols liberally. Their advanced treatises are incomprehensible to those unacquainted with their terminology, but the simpler ideas of science can be presented in straightforward unambiguous prose and, indeed, it is necessary that they should be set out in this manner for elementary teaching purposes.

For a proper understanding of scientific writing it is perhaps best to attempt a short analysis of language. From what was presumably a simple beginning, language has become a most complicated medium of communication, and even to-day it retains some of its primitive characteristics. One of its earliest developments must have been the giving of names to persons and things. It is easy to understand how onomatopoeic names, such as "cuckoo", which suggest a sound characteristic of the thing named, came to be identified with the source of the sound. In such cases the name is not arbitrarily chosen, but is derived directly from the thing. An extension of this process to other things or persons served to identify them, too, with their names. Thus these names came to be regarded as an inevitable and inseparable part of the thing or person named. The name was not only identified with the thing, but was regarded also as a kind of subtle emanation from it. Thus it was forbidden to mention some names, usually those of deities or devils, lest uncontrollable forces should be loosed. Words had power. There grew up a system of taboos, spells, incantations, invocations and exorcisms which must have added greatly to the complications of life and have served the useful purpose of keeping the ignorant in their place when they were inclined to be

inquisitive or rebellious. This attitude of superstition survives to some degree. Names are still regarded by some people as more than detachable labels; they are thought to have some effect on the course of events. Shakespeare is known to have commented on the situation. Consider a modern example: the naming of the ships of the Royal Navy is done with great circumspection, traditional names being given to a succession of warships through the centuries. Sometimes names are spoken of as appropriate, as in the saying, "The divine is rightly so-called". The man of science must not fall a victim to the power of words. It may be remembered that the White Knight, who lacked judgment in many respects, was not deceived on this point, as the following quotation shows:

> "The name of the song is called 'Haddocks' Eyes'."
>
> "Oh, that's the name of the song, is it?" Alice said, trying to feel interested.
>
> "No, you don't understand," the Knight said, looking a little vexed. "That's what the name is *called*. The name really is 'The Aged Aged Man'."
>
> "Then I ought to have said 'That's what the *song* is called'?" Alice corrected herself.
>
> "No, you oughtn't: that's quite another thing! The *song* is called 'Ways and Means': but that's only what it's *called*, you know!"
>
> "Well, what *is* the song then?" said Alice, who was by this time completely bewildered.
>
> "I was coming to that," the Knight said. "The song really *is* 'A-sitting On a Gate': and the tune's my own invention."

The primitive idea seems to have been that from the existence of names the existence of the thing could be inferred, but it will be found on investigation that many names, using the word in its widest sense, are allotted on linguistic grounds for purposes of communication, or as an aid to thought, and have no reference to things at all. They

refer to qualities which have no existence apart from the things possessing them, except in so far as they are abstracted from them in thought. These qualities are often generalised and are accorded the status of a "thing", thus leading to a theory of "universals". Consider, for instance, the word "courage". Some actions may be fittingly described as courageous, and in order to economise both thought and speech, the attribute of being brave or courageous is frequently treated as if it had existence apart from individual courageous actions. To say "he has courage" is equivalent to saying "he is a man who performs courageous actions", but the former locution is shorter, more compact and more popular. For linguistic purposes the attribute of an action has been turned into a substantive.

It is a mistake to suppose that there is an entity corresponding to each word which is used as a name. If we take the word "thing" to refer to any object of thought and "entity" to refer to those things with regard to which the reference has been or can be verified, we can distinguish between the status of three classes of "things": entities, hypothetical entities, and pseudo-entities. It is the status of the entities with which science concerns itself that is of interest to us here. A particular grain of sand is an entity. So are heat, energy and magnetism. Atoms and electrons are hypothetical entities that have almost attained the full status of entity. The neutrino and the meson have perhaps not yet quite attained this status. Phlogiston, the philosopher's stone, and the homunculus of some of the early microscopists are pseudo-entities.

Analysis of Language. It has already been said that language is the chief means of communication between human beings, but because of the diversity of our interests, the system of communication now in use has become exceedingly complicated and is liable to lead to failures. The cases of breakdown in our attempts to convey meaning are due in part to a failure to recognise the two different functions which language has, and in part to the multiple or vague meanings which words possess. The two functions of language are distinguished as:

(1) Symbolic[1] or Informative,
(2) Emotive.

(1) Words may be used to refer to things, or to symbolise them. The user's intention is to convey information to others about situations, or the relations existing between things. This may be called the informative use of language and is essential for the continuance of ordinary human relations. It is the use intended by the authors of commands, legal documents and scientific treatises. Economy of effort is attained by giving perfectly definite class-names to common objects. Ambiguity is avoided as far as possible, fine shades being indicated by the addition of more words of definite meaning. No attempt is made to play upon the feelings of the hearer, or to deceive him, or to persuade him to accept a value-judgment. This informative use of language is necessary when it is required to record facts or to give instructions for the control of future situations. In scientific writing or speech a precise situation has to be described in such a way as to render its apprehension universally possible. No value-judgments are recorded. The feelings of the author about this situation or any other are rigidly excluded as being irrelevant. The special scientific vocabulary which has been built up contains many words which are also in current use among non-scientific persons, but if these words have been adopted as technical terms in science they have one meaning only when used in scientific writing. Their other uses may be regarded as metaphorical.

(2) Words may be used to express their author's attitude, or to arouse an attitude in the listener. This is called the emotive use of language. Obvious examples are furnished by poetry, jokes and imprecations. The various kinds of oratory, political, pulpit and forensic, are all intended to arouse an attitude on the part of the listener by the use of emotionally toned words. Even the word "scientific" can be used with an emotive significance, as when ordinary

[1]Ogden C. K. and Richards, I. A.: *The Meaning of Meaning*, p. 10 *et passim*, 2nd Edition, 1927 (Kegan Paul).

actions are said to be performed scientifically. We hear of scientific batsmen and footballers. The word is used metaphorically as a term of approval, indicating that such qualities as thoughtfulness and being guided by reason, which are the mark of successful scientific work, are also to be found among certain games-players.

Social chatter, which so often seems to be of no consequence at all, may be regarded as another example of the emotive use of language. The giving of opinions in turn on matters of little significance establishes a comfortable feeling of unanimity of outlook. For instance, we readily agree in expressing our amused tolerance of the vagaries of the English climate, our considered opinion of the difficulties of post-war catering, our approval of the latest public idol or our execration of the latest public enemy. Or, if we do not agree, it is felt to be politic in the interests of social harmony to feign agreement on such slight topics. The use of small-talk is to promote a general feeling of security among a group of friends or strangers, by preliminary exchange of trivial opinions.

The two subdivisions of the use of language are by no means sharp. A single sentence may be both symbolic and emotive. Words may be given added or altered significance by an inflexion of the voice, by an accompanying gesture, or by a change in the usual order of the words in a sentence. Defending counsel in a criminal case, for instance, when addressing a jury, often uses a mixture of symbolic and emotive language. He states facts which are common ground both to the defence and to the prosecution, although he tends to stress that aspect of the facts which is favourable to his client. He also frequently makes an impassioned appeal, using the most emotive terms at his command, with the intention of assisting his client by arousing the sympathetic feelings of the jury.

Our concern will be with words used in their symbolic or informative sense, but it is by no means always easy to recognise in which sense words are to be taken. The difficulties which arise in understanding the use of words may be traced to four main sources:

(1) A word may be used simply because it is current, without the user knowing at all accurately to what it refers. For instance, the word for the practical unit of electrical pressure, the volt, is frequently misused. An ignorant reporter may write "six hundred volts passed through his body". The public repeats the phrase, not understanding that electrical pressure cannot correctly be said to pass through anything. The word "shock", in the medical sense, is seldom understood by the layman. Vitamins, hormones, iodine, allergy, are all terms in the vocabulary of modern word-magic.

(2) A word may have some association which gives it psychological but not symbolic significance. We may, for instance, have had held up to us the ideals of absolute truth or absolute good, and although we cannot arrive at any very precise definition of these terms, our conduct may be greatly affected by their existence as ideals.

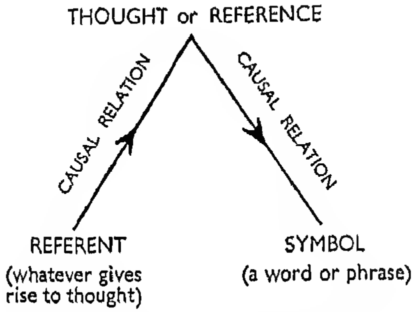
(3) A word may be used to refer to a quality as if it were an entity, that is to say, to that which may be said to possess qualities. This process is technically called hypostatisation. It accounts for most of the confusions of metaphysics and is to be strenuously combated. Colour and hardness are qualities, or attributes, not entities. A cricket-ball may be said to have these qualities, but redness and hardness have no existence apart from red things and hard things. The word "colour" which is a contraction for "the class of colours", is a linguistic device and should be recognised as such. It is part of the machinery of thought.

(4) A word may be used symbolically and emotively at the same time. On some occasions there is no confusion. Sometimes confusion arises unwittingly, or it may be fostered by the speaker. The phrase "the flag of England" may be used because of its emotional appeal, or as a symbol for a rectangle of white cloth marked, in a manner familiar to most Englishmen, with a device in red and blue. The influence of language upon thought is so far-reaching that it has become very difficult for a user of language for scientific purposes to select words which have a symbolic significance only, and it is this difficulty in the use of words which must be resolved.

We may recognise three constituents in the act of communicating our impressions of the outside world to another person. We have thoughts about things and we express our thoughts in words. "Things" and "words" are terms which are too vague for our present purpose and technical terms will have to be introduced. Words will be known as *symbols*. Since they refer to things, the thought which gives rise to the symbol may be called a *reference*, but it will not be necessary to employ this particular term very often in the following discussion. The thing referred to will be known as the *referent*. Thus, instead of saying that we have thoughts about things and we express our thoughts in words, we can now substitute "our thoughts about referents give rise to symbols" or some similar locution, remembering that a symbol may be either a phrase or a single word. The substitution of referent for thing overcomes the difficulty that the word "thing" is popularly restricted to material objects, whereas we intend it to stand for whatever is being thought of or referred to.

It is the relation between symbols and their referents which we have to discuss. A referent may be said to cause my thought about it. An orange placed before my open eyes may quite legitimately be said to cause my recognition of it, just as the bringing-up of a magnet to a compass-needle may be said to cause the deflection of the needle. The attacks of philosophers on the notion of causality may be ignored for our purpose as the difficulties cease to obtrude themselves when it is realised that the word cause is a contracted symbol for a type of relation between events which is of very frequent occurrence. Even though "cause" were shown to be an unanalysable relation, it would still remain a useful aid to thought, both in everyday life and in the sciences. If my situation is such that I wish to communicate my recognition of the particular referent whose nature has been disclosed above, I use the word or symbol "orange". In doing so, a second causal relation is to be discovered. Not only does the orange cause my thought about it, but my thought is also the cause of the symbol. It is true that I could have

recognised the orange without calling the symbol into being, but since the psychological situation was such that a symbol was evoked, it is sufficiently accurate to say that the thought caused the symbol, even if other factors in the situation also influenced my action. The twofold indirect relation between symbol and referent is clearly shown in a diagram:



Modified from C. K. Ogden and I. A. Richards, *The Meaning of Meaning*, p. 11.

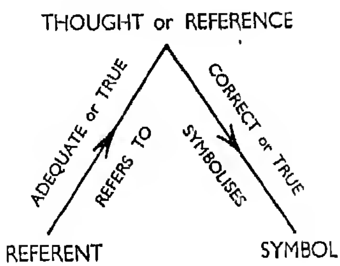
It must be noticed that the base of the triangle is not filled in. There is no direct connection between the symbol and its referent, except in the case of onomatopoeic words. Most of the difficulties which arise when we try to think accurately are due to the tacit assumption that the base of the triangle is filled in. When we say that a word means something, we tend, for reasons of brevity and custom, to assume that a unique, direct relation exists between the word and the thing. But herein lies a possible source of grave error. As Ogden and Richards say: "Normally, whenever we hear anything said we spring spontaneously to an immediate conclusion, namely, that the speaker is referring to what we should be referring to were we speaking the words ourselves."[1] Sometimes our referent is the same as that of the person speaking, but it is not always so. We tend to forget that the act of communication involves not only a thought

[1] Op. cit., p. 15.

process connecting the symbol with the referent in our own case, but also a second thought process connecting the symbol with the referent must be carried out by the other party to the act of communication. Either or both of these thought processes may be inadequate, with the result that my referent is not your referent and communication has failed.

Let us consider the baseless triangle again. The left-hand side shows diagrammatically that a referent is in a causal relation to a thought. The referent may be an external thing or object, such as an orange, which causes modifications in my sense organs of such a kind as to result in a thought, but there is nothing to guarantee the adequacy of my thought. My sense organs may be of poor quality or may be deranged in some way, so that an inadequate thought or a mistake arises. When the thought caused by the referent is adequate it may be said to be true, but it should be noted that "adequate" is an inexact term and requires expansion.

The right-hand side of the triangle shows that a thought can be in a causal relation to a symbol. Again there is the possibility of a mistake. The thinking apparatus, whatever that may be (it would be gratuitous to make any assumptions about its nature: all we know is that it works), may, for a variety of reasons, give rise to an incorrect symbol for the referent in question. When the symbol is agreed to be correct it may be said to be true, the test of correctness again being pragmatic. When and only when both causal relations have been judged to be true can it be said that the true symbol for the referent has been found.



The simplest case of reference will be that of the perception of an ordinary object external to ourselves. Other cases, and at the higher levels of thought they will be the majority, will not need special consideration from us, once a simple case of perception has been understood, for, when the referent is itself a symbol, it is reached by a series of steps which is not difficult to follow. Suppose I am reading about Sir Isaac Newton. My relation with him can only be indirect, since he died in 1727. Yet, by a series of steps he can be the referent to which my thought refers. The steps are: the words of the book—historian—contemporary record—eye-witness—referent (Newton). In the same way the thoughts of others, now living or long dead, can be referents which cause thoughts in me, here and now.

Sign-Situations. It is common knowledge that when our eyes are open we can focus our attention on any part of the field of view before us. If an object in the field of view is in motion our attention is naturally turned to it. The moving object may, perhaps, be a sign of danger. Similarly an unexpected sound may be the sign of a disturbance in our environment, whether it is due to the scratching of a mouse or to the careful tread of a burglar. The moving object and the unexpected sound are external stimuli and it is such stimuli that give rise to all our experiences. Stimuli are of two kinds:

(1) They may fail to arouse thought, in which case they bring about what may be called mere experiences. My sensation of warmth when I am sitting before a fire is an example. The stimulus causes a pleasant feeling, but it does not necessarily arouse thought.

(2) They may give rise to thought, in which case the stimulus is said to be interpreted. A stimulus which is interpreted is called a *sign.* Things seen, sounds, feelings of pain and pleasure, can all be signs. The number of the front-door of a house may be interpreted as a sign of the house I am looking for. The report that a telescope had been invented in Holland was a sign for Galileo. It aroused thoughts in him which resulted in his invention of a better telescope.

The way in which a sign is interpreted, that is to say, its effect upon a person, will depend upon his past experience. If I strike the keyboard of a piano, the ivory keys and my act of striking are present stimuli. I expect a sound or a series of sounds. My expectation could not have been the same if I had had no experience of the keyboard of a piano before. Past strikings of keyboards must have brought about some modification of my mental apparatus, thereby leaving tracks or traces, which will facilitate my thought processes when similar situations arise in the future. The situation involving the piano, my striking of it, and the resulting sound, may be called a *context.* This external context is accompanied by a sensation of pressure in my finger-tip, an expectation of a characteristic sound, and a sound-sensation. These three constitute the psychological or internal context. There may be other psychological contexts also affecting my interpretation, but for purposes of simplicity they will not be considered here. When can my interpretation be regarded as true? In order to answer this question we shall have to return to the original stimulus.

A stimulus always provokes some reaction, which may be called an adaptation to it. A trace or record of this is left in our organisation so that, when the stimulus occurs again, or a similar stimulus occurs, or perhaps only part of the stimulus, the same adaptation takes place. If in the past I have on one occasion taken hold of a red-hot poker, I withdraw my hand automatically without touching any similar pokers which may subsequently be presented to me. Thus a sign, which is part only, perhaps, of an external context, gives rise to, produces, provokes, or causes a thought or reference similar to that caused by the original complete stimulus. Part only of an external context (the sign) thus causes a complete psychological context (a thought or reference). If the psychological context links up nearly completely with the external context, the thought may be called *true*. If it does not do so, the thought is *false*. The test of truth must be the comparison, item by item, of the parts of the external and the psychological contexts.

All other cases of interpretation can be treated in the same way, although the discovery of the elements of the contexts may be very difficult and the assessment of the degree of completeness of the linkage may be assailed by critics. A scientific datum is a sign of an external context, the more or less skilful interpretation of which is the work of the scientist. For success in this work he needs mental acuteness and much experience of similar contexts. Sometimes new signs are seen and new contexts have to be analysed. The discovery of radioactivity was a sign whose context required ten years for elucidation in the able hands of Rutherford and Soddy. It is painstaking dissection of contexts, tedious though it is in most cases and incomplete in others because of the nature of the referent, that has led to an undeniable measure of success in the sciences and in other fields of practical investigation.

Symbols. We have seen that when a sign, which is usually only a part of an external context, is interpreted, it gives rise to or causes a psychological context, one member of which may be called a thought. Suppose I am the interpreter of such a sign. Two possibilities are open to me. I may decide to do nothing, or I may decide that some further activity on my part is demanded. This activity may be physical, consisting of bodily movements only; it may be mental, consisting of the pursuit of a train of thought; or, perhaps, I may decide to communicate with my fellow men. For this last purpose I must give a sign, recognisable by my fellows, which becomes a stimulus for them, effective in producing a psychological context in them which is as similar as possible to my own psychological context. These signs used in communication are of two kinds. The first and more primitive class consists of gestures, mimetic sounds, diagrams and images. The second class are linguistic signs or *symbols*. It is these which constitute language, provided that there is some agreement among a group of men as to what symbols shall be used and provided that certain rules, usually called grammar, are obeyed in the construction of compound symbols or sentences. So far as communication is concerned, thinking consists not only of the interpretation of signs,

but also of the selection of appropriate symbols. A diagram may be of assistance at this point:

SIGNS IN COMMUNICATION

Signs, usually part only of an external context,

↓ are interpreted, causing

THINKING

an internal context, i.e., a thought or reference, and

↓ if communication has been willed,

a sign is selected for use.

Symbolic	Non-symbolic
Linguistic signs or symbols, often aided and elucidated by	Gestures, images, mimetic sounds, diagrams.

In scientific writing linguistic signs are frequently illustrated, clarified and reinforced by the use of diagrams and mathematical symbols, using the word symbol in a narrow specialist sense. Their purpose is to reduce the risk of a failure in communication.

The account of thinking outlined above has no place for the existence of occult relations between things, thoughts and words. Things cause thoughts, which, in some circumstances, cause words. The adequacy of the interpretation between the thing and the thought is open to careful investigation of the kind used in the sciences, and the selection of words used in communication is susceptible of a careful scrutiny of a similar kind.

Each man is free to construct symbols for himself and to endeavour to establish communication with his fellows by

means of them. Hence there are frequent failures to convey the intended meaning, but the risk of misunderstanding is one which most men seem to be quite prepared to take. The growth of language is due to those who take such a risk successfully and is subject to the demand for a new symbol to fill a need. Ultimately the acceptance of new symbols depends on the taste of the community which adopts them, but with the progress of discovery and invention and its attendant increase in the complexity of thought, many things receive names without there being any obvious method of identifying the symbol with its referent. A symbol, originally used legitimately and effectively, is often misused as time goes on. The same symbol may be used for different referents and thus confusion arises. Further, many symbols are contracted. This is in part due to the need for economising words in human intercourse, lest our listeners should become bored and should cease to pay attention. Confusion is also frequently due to the attempt to convert others to our opinions by adding emotive significance to our symbols, which are thereby intended to arouse in our listeners the same attitude that we ourselves have towards the referent in question.

The process of choosing symbols may be called symbolization. Six rules or postulates, called the Canons of Symbolism, have been stated by Ogden and Richards,[1] who claim that, if the Canons are applied systematically in the use of language, not only is a solution provided to many long-standing problems, such as the problem of truth, but also a clear prose style for purposes of reference is ensured. This is exactly what is required for scientific exposition. The Canons of Symbolism are:

(1) *The Canon of Singularity.* "One symbol stands for one and only one referent." The referent is frequently complex. The symbol "the armed forces of the Crown", for instance, has only one referent. The symbols of mathematics may have other symbols, or operations with other symbols, as referents, but we shall not digress into a discussion of the nature of mathematics. When a symbol seems to have more

[1] Op. cit., p. 88.

than one referent it is contracted. The expansion of "port" to "port wine" at once serves to distinguish its referent from that of "port", a harbour.

(2) *The Canon of Definition.* "Symbols which can be substituted for one another symbolize the same reference." This Canon is of the utmost importance and is discussed later. We have to guard against those cases where two symbols have the same referent, but do not symbolize the same reference. In the well-known Irish epitaph, Robert Boyle is described as "the father of chemistry and the uncle of the Earl of Cork", a pleasing conjunction of relationships in which the great chemist is the only referent, but the psychological context or reference is different in the two phrases. The symbols are therefore not substitutes for one another in the sense demanded by this Canon.

(3) *The Canon of Expansion.* "The referent of a contracted symbol is the referent of that symbol expanded." This Canon indicates the method that should be employed for identifying symbols with their referents. The disputed symbol should be expanded in all possible directions until the sign-situation which caused the reference has been discovered. If the referent is an external object, say a penny, and we have some knowledge of physics, the expansion may take us as far as electrons and protons, thus: cone of vision—surface—design—coin—penny—metal—alloy—copper-and-tin—atoms—electrons-and-protons, etc. The difficulty that will arise will be that of deciding the level of reference intended by the user of the symbol. For ordinary purposes, perhaps, it is enough to know that a penny is made of bronze, a chemist may be interested in its constituent atoms and a physicist in the constituents of the atoms. These different interests illustrate levels of reference.

Much of the confusion encountered in the use of symbols is due to a failure to expand doubtful symbols with sufficient care. Contractions and false expansions lead to the creation of pseudo-symbols which have no referents. Nevertheless, such referents are assumed to exist and the discussions they have provoked, which have filled many volumes, are known

as philosophy. One such philosophical question is the "problem of truth", but it should now be clear that there need be no such problem. In a discussion of the question of the truth of symbols, Ogden and Richards say, "Instead of treating each case of adequacy on its own merits, epistemologists will have it that because they can use one word as a convenient shorthand sign to refer to all true symbols, there must be something for them to investigate apart from true and false propositions. No problem arises over any true proposition when recognised as such, and to raise a bogus problem here is quite as unnecessary as to assume a universal 'redness' because red things are every one of them red."[1]

Propositions may possess the attribute of being true or may lack this attribute. It cannot be too strongly emphasised that there is no single referent for the word truth, which cannot therefore correctly be called a symbol. The word is a class name for an attribute of all true propositions, and may be looked upon as one example of a linguistic or methodological device. As such it is a valuable item in the machinery of symbolism.

(4) *The Canon of Actuality.* "A symbol refers to what it is actually used to refer to: not necessarily to what it ought in good usage, or is intended by an interpreter, or is intended by the user to refer to." It would be as well at this point to distinguish between a true symbol and a true reference. A true symbol is one which correctly records an adequate reference. It is usually a proposition, and it correctly records an adequate reference when it is capable of causing a similar reference in a suitable interpreter. The incorrectness of a symbol may be partial only. If I say "that note was the middle C of a piano" when my sensation of sound was in fact due to a saxophone, my symbol may have correctly characterised the referent as "middle C", but it has failed to place it among the various sounds which, although they are all correctly called "middle C", are due to different instruments.

[1] Op. cit., p. 95.

The Canon of Actuality is necessary because, if an efficient system of clear symbols is to be constructed, safeguards are required to prevent vagueness and confusion. In cases of difficulty the full circumstances of a doubtful or ambiguous symbolisation must be investigated and, if necessary, the symbol must be improved. The test of correct symbolisation can only be experience. If, for example, I wish to symbolize musical sounds correctly, I can hardly hope to succeed unless I have had experience of the characteristic sounds produced by different musical instruments.

(5) *The Canon of Compatibility.* "No complex symbol may contain constituent symbols which claim the same 'place'." Again experience is the test. From the time of our earliest attempts to recognise and describe our environment, we have accumulated vast stores of information about things and their qualities. We become aware that, if an object is correctly described as having one particular quality, there are other qualities which it is thereby excluded from having. If a thing is correctly described as blue it cannot also be red. The propositions "this book is blue", "this book is green", and "this book is red" all claim the same "place" for their referents. Without modification or expansion, no thinker would make any two of these assertions about the same book. But he might justifiably say "this book is both blue and expensive", for no conflicting claims can arise with regard to the "places" of a colour and a price.

(6) *The Canon of Individuality.* "All possible referents together form an order, such that every referent has one 'place' only in that order." This Canon sums up and replaces the three Laws of Thought which have for hundreds of years either greatly exercised logicians, or have been ignored by them as unmanageable. When these laws are translated into the language of symbolism, their value as guides to him who would keep his discourse free from nonsense is obvious enough. The Law of Identity may be written "Every symbol has a referent", instead of "A is A". The Law of Contradiction may be written "No referent has more than one 'place' in the whole order of referents", instead of

"A cannot both be A and not be A". The Law of Excluded Middle may be written "Every referent has a fixed 'place' in the whole order of referents", instead of "Everything must either be A or not be A".

In any false assertion it is necessary to distinguish two things: (1) the referent to which we are actually referring and (2) an alleged referent to which we believe ourselves to be referring. It is the first of these which has a "place" in the whole order of referents. "Place" must be regarded as part of the symbolic machinery, rather than as itself a symbol. A symbol is said to have a "place" for convenience of expression, for "places" have no existence apart from the referents which fill them. Alleged but non-existent referents have no "place" at all.

These six Canons, which are the fundamental postulates of what Ogden and Richards call Symbolism, are a complete substitute for Formal Logic, in that they are capable of succeeding where Formal Logic has failed. They ensure the correct use of words in reasoning and suggest a course of action whereby ambiguities may be resolved. They are applicable to all our reasonings about the outside world and help us to recognise those cases where we are in danger of introducing indefinable or mysterious entities. They are not required for the ordering of our affective life. They are, in fact, singularly unhelpful in assisting us to frame a proposal of marriage, or to criticise a work of art, or to write a poem. Although the Canons of Symbolism sternly forbid us to enter the pleasant and seductive realm of emotive language, they confer on us the power of communicating our thoughts to our fellow men with a reasonable degree of accuracy and of describing our experiences of nature in such terms as have made the growth of science possible.

Definition. The majority of people outside academic circles are not only strangers to the practice of defining their terms, but are also unaware that a great many of the most useful words such as "meaning" and "truth", are not single symbols at all. They are homonyms. The various applications of such words are frequently quite unlike one

another and would, in a rationally constructed language, be expressed accordingly. But it is just these words of great antiquity which have failed to change with the growing complexity of thought. In the sciences the finest shades of thought are indicated by the introduction of new terms. In the early development of language, widely divergent lines of thought were often designated by the same word. The examples of this curious inability of language to expand when demand arises are numerous, but the two of them which will engage our attention in the sequel are "meaning" and "truth".

A notable feature of science is its universality. Those of its principles which are accepted in London, England, and in Berkeley, California, are equally acceptable in Tokio or in Berlin. The terms "atom" and "energy" are equally well understood wherever it is the business of men to use them. No other branch of knowledge can show this widespread unanimity. The writings of a Plato, a Spinoza, or a Hegel cannot be brought into agreement even after much commentary and interpretation. Again, there are several types of ethical theory. Religious and political dogmas are even more diverse. It is possibly the nature of the subject-matter of philosophy, religion and politics, being concerned, as they are, with abstractions or with the operations of the human will, that prevents the growth of a single firmly established body of doctrine upon which an expanding superstructure can be built. It is perhaps the very concreteness and tangibility of much of the material of science that gives compulsive force to its utterances, together with the undeniable fact, which is plain for all men to see, that science works. Only those assertions which are demonstrable are labelled as facts, the rest being regarded as more or less probable. This state of affairs and, therefore, much of the success of science, can be traced to the scientists' habit of careful definition of technical terms, which thereby guarantee the interchange of meaning between different workers in the same field. It will be worth while to investigate the available methods of framing definitions, but

we must first of all be clear as to what it is that we propose to define. There are two quite different possibilities:

(1) We may wish to define words (or symbols).
(2) We may wish to define things (or referents).

In order to define a word it is required to substitute a word or set of words which will be better understood, in a given situation, than the original word. We are required to find an alternative symbol for a given referent which, in the circumstances, is an improvement on the symbol it displaces. No information about things is conveyed in defining words, although information is given about symbols. If my hearer is uncertain of the nature of my referent when I use the symbol "petrol", I may be more successful in my attempt at communication if I substitute the symbol "gasoline". When I say "petrol is gasoline" I am, by common consent, using a contracted form of the statement that "petrol" and "gasoline" both stand for the same referent. The definition of a word is therefore either translation or the selection of a suitable synonym.

In defining things, on the other hand, my aim is to expand the symbol by enumerating certain properties of the referent which will serve to distinguish it from all other referents. If I select the expansion "petrol is motor-fuel", I am giving information about the use of petrol. If I say "petrol is a mixture of liquid hydrocarbons which is used as a motor-fuel", I am giving additional information about its composition. These expanded symbols widen the reference and assist in the identification of the referent.

Although definitions of words are in frequent demand, it is often impossible to supply them without giving information about the referent at the same time. Occasionally there is no synonym in existence; but if there is, communication may well be facilitated by its use. If no synonym can be found, a simple statement of the function of the referent may serve the purpose. If my definition "petrol is gasoline" is not understood, it is at least possible that "petrol is

motor-fuel" will be. The authors of dictionaries, who usually work to a historical plan, find themselves bound to use both kinds of definition indiscriminately. Sometimes a dictionary definition consists of a number of synonyms, or approximate synonyms, for it is doubtful if complete synonyms occur. (They would be pairs of words which are alike in all their functions.) If it is impossible to arrive at a definition of this kind, or if such a definition is deemed to be inadequate, the lexicographer frequently supplies clues for the identification of the referent. In other words, he defines the thing. Because of the varied uses to which a word may be put, or has in the past been put, several definitions of a single word may be given, which involves the user of a dictionary in an act of selection. This is, of course, obvious, but it is worth stating here because it emphasises the fact that when definitions are used they must be relevant to a particular situation. Definitions are always made for some human purpose and in consequence they are as a rule only applicable to some restricted field of discussion, or, as it is called technically, to some "universe of discourse". The definition of "equation" in mathematics is quite different from that which would be required to explain the phrase "personal equation", because the universe of discourse is different. When a term is applied outside the universe of discourse for which it has been defined, it becomes a metaphor and will need a second definition. If I say "He never put a foot wrong" I am not necessarily referring to a horse, nor indeed, to a foot.

Not all assertions are definitions. "Clocks are machines" and "Clocks are ornaments" are assertions of different types. The first is a definition and is seen to be true as soon as it is understood, for the definition of machine includes that of clock. That "Clocks are ornaments" may be doubted. It would be necessary to inspect a clock before agreeing about its ornamental nature. The definition of clock does not include the definition of ornament and the assertion "Clocks are ornaments" is made by an act of private judgment. The difference between the two types of

assertion must be looked for in the references, which are different. We shall be misled if we rely on the form of words alone.

Now that these preliminary points have been to some extent cleared up, it becomes possible to describe the technique of definition, that is to say, to give an account of how we define. Since, by Canon 4, we know that a symbol refers to what it has actually been used to refer to, it is apparent that in all cases what we have to do is to find the referent. This is easy enough in theory. All that is necessary is to find some set of referents about which agreement can be obtained and then to locate the required referent by means of its connections or relations with these agreed referents. Luckily, the number of these defining relations in common use is not very large, although others may be required for special purposes. Obviously the starting point of a definition must be familiar, or the definition will fail to be of any use. In making the more fundamental definitions it is not enough, as a rule, merely to refer to a symbol as the starting point, because it is difficult to be quite certain that my own referent and my hearer's referent are the same. It is better and safer to use something which can be indicated by a gesture or by reference to some common universal experience. If, for example, in the universe of discourse of elementary physics, I wish to define "power" I might say: "Power is rate of doing work". Perhaps my hearer understands this fairly well, but is vague about the term "work". I then say: "Work is done when a force moves its point of application". He understands all this except what a "force" is. I therefore demonstrate the application of a force to a heavy object by pushing it, saying: "Force is that which causes change of speed of the heavy object", and my hearer is then able to identify the referent correctly. The starting-point of the definition is a sign which leads to the required referent.

In order to arrive at a definition our task is to state the more obvious relations in which the required referent stands to some known referent. The number of such relations

which are used in practice is not very large and may be summarized in the following list:[1]

(1) Symbolization. The simplest way of defining is by the direct naming of an object. If an illiterate friend says: "What is a book?" I can perhaps best meet the situation by handing him one, saying: "This is a book." If I wish my instruction to be general instead of particular, I shall have to introduce a second defining relation, that of similarity.

(2) Similarity. I may say: "Not only is this a book, but all other things which are similar in respect of material and construction are also books; to all of these the symbol 'book' can be applied." It is these similarity relations which give us a simple and effective means of defining concrete referents and which so often satisfy our curiosity.

(3) Spatial Relations. "A book is a portable written or printed treatise filling a number of sheets joined hingewise and enclosed in a cover." "Joined hingewise", "enclosed in" are spatial relations, as are on, above, between, beside and many others.

(4) Temporal Relations. "The very witching time of night" is defined in *Hamlet* as "when churchyards yawn and hell itself breathes out contagion to this world". Only occasions can be defined by temporal relations, but there is apparently a natural tendency on the part of the uninstructed to start a definition of almost any kind with the phrase "X is when", however inappropriate the use of the temporal relation may be. This form of definition is, of course, sometimes correct, as in "Christmas is the season when greetings and unsolicited artefacts are indiscriminately exchanged". Other temporal relations are expressed by such words as before, after, sooner, during, etc.

(5) Causation. (*a*) Physical. "Tides are periodic movements of the sea caused by the attraction of the moon." "The cold of winter is a phenomenon caused by the obliquity of the sun's rays."

(*b*) Psychological. "Instinct is what causes those seemingly rational acts which are performed without conscious design."

[1] Op. cit., p. 117.

"Fear is a painful emotion caused by impending danger or evil."

(*c*) Psycho-physical. "Taste is a sensation caused by the stimulation of certain organs in the mouth by means of some soluble substances." "Sight is caused by the absorption of light-quanta in the retina of the eye." It may be noted that causal relations are very frequently employed for the purpose of definition, both in general discussion and in the sciences.

(6) Being the object of a mental state. Desiring, hating, willing, sympathising, referring are examples. "Good things are those of which we approve of approving." "An ambitious man is one who ardently desires distinction."

(7) Legal relations. A great many definitions are made up of two or more of the above relations. Legal definitions are also complex, but are worth mentioning as a class because the legal relation can be tested by the arbitrary method of appealing to a judge. "Owned by", "liable to", "evidence of" are examples. "Barratry" is defined as "vexatious litigation", but whether litigation is vexatious or not can only be decided by a court of law.

The above classification is not exhaustive, but it will be found to contain most of the defining relations which are commonly used. The purpose of definition is strictly practical. If controversy and discussion are to lead to any agreement, or if co-operation is required for the solution of any problem, it is essential that the parties concerned should start with the same referent or set of referents. In the physical sciences, which deal with the simplest aspects of nature, very great care is taken to define the fundamental symbols; and these definitions, when agreed upon, are kept constantly in mind by scientific workers. In other branches of intellectual activity definition is not usually so rigid, nor is it forbidden to attempt the conversion of others to a favourite point of view by the use of emotive language. It is an outstanding characteristic of scientific writing that the symbolic function of language is employed to the total exclusion of the emotive.

Meaning. This word has been put to many uses and therefore has as many definitions, the most important of which are given below. It will be noticed, that in some of the definitions meaning is ascribed to things, but that in others it is the meaning of words that is under discussion. In some cases meaning has been adopted as a technical term by philosophical writers and in other cases it has been used as a synonym in everyday speech for quite clearly defined notions. The application of the Theory of Signs gives rise to a further crop of definitions.

(1) "Meaning is an intrinsic property of things." A tree or a building has certain qualities or properties such as colour, hardness and shape. In addition, it is alleged, there is another and wholly mysterious property which is identifiable as its meaning. This may be so, but meaning in this sense has not yet succeeded in establishing itself among the properties of things which science is prepared to notice, although it may be of emotive significance.

(2) "Meaning is an unique unanalysable relation which may exist between things." "The meaning of life is to be found in its potentialities." Here the relation between life and its potentialities is labelled the meaning of life. Presumably any other pairs of things which can be shown to be connected in the same way will also be in the relation of meaning to one another. Unanalysable relations are not employed in science.

(3) "Meaning is defined as the other words which immediately follow the alphabetically arranged words in a dictionary." This definition is widely and correctly used in its own universe of discourse, especially for deciding the Good Use of a symbol. We have already seen that dictionary meanings are either approximate synonyms or are attempts to locate a referent.

(4) "Meaning is the connotation of a word." This is the "meaning" of Formal Logic. It has been claimed that a symbol may have meaning in two senses: (*a*) it may mean the set of things to which it can correctly be applied, or (*b*) it may mean the properties of the thing which determine

the choice of symbol. The first of these is called denotation and the second is called connotation. Much argument has arisen about these terms but they are now becoming obsolete. It should be remembered that the real world consists of things-possessing-properties and that the properties can only be separated from the things in thought. A property taken by itself should be regarded as part of the machinery of symbolism.

(5) "Meaning is an essence." This appears to be either a special property of a thing hypostatised, that is, illegitimately taken as a thing, or else the sum of its properties hypostatised. Frequent warnings against the invention of spurious entities in this way have already been given.

(6) "Meaning is an activity projected into an object." If the meaning of a piece of music is projected into it by the listener, it looks very much as if the causal theory of signs discussed above will have to be abandoned; but perhaps this definition is only a metaphorical inversion of the more plausible view that a mental effect is caused by an external stimulus.

(7) "Meaning is an event intended or willed." "I meant to go to the wedding" is equivalent to "I intended to go to the wedding". "He means well" is equivalent to "He intends (but fails) to do well". This is a case of the substitution of the word "means" for "intends", the use of "meaning" being quite different from that involved when "intention" cannot be substituted for "meaning". Ambiguity may arise in the careless or disingenuous use of such phrases as "What I meant was X", because there is nothing to show whether "What I meant was X" is equivalent to "What I intended to refer to was X" or "What I intended you to refer to was X". Expansion of the symbol used is the remedy. "Meaning" may also be equivalent to "purpose" or "significance".

(8) "Meaning is the place of anything in a system." When the place of anything in a system has been found, it is sometimes said that its meaning has been grasped, as in "The meaning of the planetary motions was finally arrived at by the discovery of the law of universal gravitation".

(9) "Meaning is defined as the practical consequences of a thing in our future experience." Those propositions are said by Pragmatists to have meanings which gives rise to practical consequences in the future. Those which have no practical consequences have no meaning. This is a technical use of meaning which is not very much in favour.

(10) "Meaning is defined as the theoretical consequences of a proposition." Here "means" is a synonym for "involves" or "implies". "Protection means that your bread will cost you more." This use of meaning is very common in argument.

(11) "Meaning is an emotion caused by anything." The word is often purely emotive, like "good" or "sublime". "If I did not believe such-and-such a dogma, life would have no meaning for me." We are unlikely to be misled by this use of meaning.

(12) "Meaning is that which is actually related to a sign by a chosen relation." This definition refers to the meaning of "things" and is implicit in the theory of signs. Any event which is a sign will be actually related, either causally or temporally or in some other way, to other events, one of which may be selected as the meaning of the sign. If I hear the middle C of a piano, I may legitimately say that the sound means either that a particular ivory key has been struck, or that a steel piano-wire is vibrating at the rate of 256 times per second.

(13) "The meaning of a sign is that to which the mental process interpreting the sign is adapted; or, that which a sign is interpreted as being of." It has been stated above that thinking is adaptation, due to the linking up of psychological contexts with elements in external contexts. In the case of simple stimuli, such as the sound of the dinner-gong, the process of adaptation is not difficult to understand. My psychological context may contain such elements as knowledge of the time of day, a sensation of hunger, and the memory of past dinners enjoyed. I hear the sound of the gong and interpret it correctly. The sound means that dinner is ready. If I hear the same sound at half-past

three in the afternoon, the psychological situation is not the same, and gives rise to a different adaptation. This time, perhaps, the sound of the gong means that my small son is again indulging in a mischievous prank.

It may prove to be very much more difficult to give a detailed account of the interpretation of more complex stimuli, such as thoughts about abstractions, but the difference is one of degree only. It is no news that meanings are sometimes difficult to grasp.

Definitions 12 and 13 give the same results for true interpretations, for the meaning of a sign adequately interpreted will be just that reference which is derived from the sign-relation, but for false interpretations the meanings will be different. Herein lies the merit of definition 13. How are we to know, if we use definition 12, that what we take to be the meaning is actually related to the sign by the chosen relation? Definition 13 stresses the act of interpretation, which is crucial. When there is difficulty in arriving at the meaning of a sign, we are bidden to dissect the internal and external contexts into their elements, until we are satisfied that the interpretation is adequate. This definition of meaning has the additional advantage of dispensing with the necessity for a "Correspondence Theory of Truth", for an adequate reference has for its referent not something which corresponds to an event, but the event itself. The meaning of the sign *is* the event. Definition 13, as applied to symbols, may be stated in the form: "The meaning of a symbol is that to which the user of the symbol actually refers."

Three further definitions of meaning must be given for the sake of completeness and to remind the reader of the difficulties of accurate communication.

(14) "The meaning of a symbol is that to which the user of the symbol ought to be referring." This definition raises the question of Good Use. The word "ought" must be expanded. We know that a correct symbol will cause a similar reference in any suitable interpreter. For a group of suitable interpreters the reference caused by a given symbol comes to be spoken of as *the* meaning of the symbol,

but it is clear that such meaning is conditional on the agreement of the interpreters, need only hold for one universe of discourse, will probably change with the lapse of time, and may vary within narrow limits. When the convention of Good Use is ignored we find ourselves in a situation similar to that of Alice in her conversation with Humpty Dumpty. No wonder she was mystified by his use of "glory" and "impenetrability".

(15) "The meaning of a symbol is that to which its user believes himself to be referring." Because symbols are sometimes thought to have intrinsic meanings, an uncritical user may believe himself to be making a reference which is not in fact the case.

(16) "The meaning of a symbol is that to which the interpreter (*a*) refers, (*b*) believes himself to be referring, (*c*) believes the user to be referring." The ascription of these three meanings gives rise to much of the difficulty experienced in attempts at accurate human communication. The last (16*c*) is a particularly rich source of misunderstanding.

The Meaning of Truth. It is now possible to discuss the meaning of truth in sufficient detail to contribute an answer to the question "Is Science true?" The Oxford English Dictionary, which is arranged on a historical plan, distinguishes twelve uses to which the word truth has been put. The first four of these are variations of the definition of truth as the quality of being true. On referring in the same dictionary to the word true, it is found that it has or has had five main uses, in four of which shades of meaning can be distinguished. The three chief meanings of truth are:

(1) Truth is "the quality of being true". It is an attribute. This definition has already been reached and involves us in a further discussion of the meaning of the word true. We shall omit obsolete uses of the word and all its meanings as applied to persons. We shall be concerned not with "the disposition to speak or act without deceit", but with the truth of scientific facts and laws.

(2) Truth is "conformity with fact; agreement with reality; accuracy; correctness; verity of statement or

thought". These are "modes of existence". They provide a useful expansion of the word truth, but give us no clue as to how the truth of a statement or thought is to be established.

(3) Truth is "something that is true". There are various senses in which this definition may be used: truth is that which is in accordance with the fact or the actual state of the case; truth may mean the real thing, as distinguished from an imitation; or religious orthodoxy; or a true statement; or an established principle. All these uses of truth as a thing are more or less convenient, if confusing, attempts to communicate the opinion that the "thing" referred to possesses the quality of being true. When a "thing" is said to be a truth, use is being made of a contracted form of the statement that the "thing" has truth among its qualities.

The word "true" is used in five main ways. We shall adopt only one of them for our purpose.

(1) True, used of persons, may mean "steadfast to a friend".

(2) True may mean "honest or sincere".

(3) True may mean "consistent with fact; agreeing with the reality; representing the thing as it is". This is the sense of "true" in which the word is of use to scientists and it has been their particular concern to establish that the agreement or representation demanded by the definition should be as close as possible. Philosophical speculation about the nature of "reality", or of "being", is to be ignored at the level of this definition.

(4) True may mean "agreeing with a standard; precise; proper; legitimate; accurately fitted". These meanings are in current use, but must be distinguished from those given in (3) above.

(5) True may mean "real; genuine; not spurious or imaginary". These meanings are also in common everyday use and need not cause confusion when encountered. The best way to find out which meaning of the word "true" is intended in speech or writing is to expand the sentence and to substitute, in turn, the five sets of homonyms given

above. An inspection of the altered sentence will then usually reveal in which sense the word "true" is being used.

If we were to follow the method in use in the sciences of indicating differences by some distinguishing mark, we might designate the symbolic or informative sense of true as True^s and the emotive or evocative sense as True^e.[1] Apart from its use in science, the word true is much employed, for instance, in art criticism or to excite an attitude on the part of a listener, but although the scheme suggested above might help to clarify the written word, no such device could be of any use in speech. The words for the different senses of true must sound different when spoken, if confusion is to be avoided.

The analysis of meaning which has been undertaken at some length in this chapter at once informs us that the sense in which "true" is to be taken, when encountered in scientific prose, is that of (3) above. The word "true" in science means "consistent with fact; agreeing with reality; representing the thing as it is". If it can be shown that the six canons of symbolism are obeyed in describing the facts of science it will be concluded that those facts are true in the sense of true which we have adopted. But we shall still be unable to decide whether science as a whole is true or not, until we have seen in what sense it is possible for the laws of science to be true. Scientific laws are built out of the facts of science, but even if the facts are known to be true, it does not follow that all the laws must be true also, for some of the laws are about relations between facts; it will also be necessary to come to some conclusion about the truth of scientific theories.

[1] Op. cit., p. 151.

CHAPTER III

SCIENCE AND TRUTH

THE WORD "science" is an unexpanded symbol which is used to refer to, among other things, a very large number of laws and theories. Many of the laws and theories of early science have been given up because they were found to be inadequate for the purpose for which they were constructed. Science is an ever-growing body of doctrine. Some of its laws have had to be modified from time to time in the light of further research, and its theories change and develop concomitantly with the laws. But many of the laws of science are well accredited. They have stood the test of time and are continuing to fulfil their purpose. They constitute the stable part of science and are to be found in all the relevant text-books. These authoritarian volumes are written by experts, men trained and experienced in the branches of knowledge they profess. It would be a mistake for the ordinary person to cavil at the contents of these volumes, for we have been reminded that when the experts agree, we, who are not experts, cannot reasonably hold the contrary opinion. It would be foolish for me to doubt the existence of cosmic rays if I have never witnessed the phenomena from which the experts have inferred their existence. In this book it will be assumed that a fair statement of scientific doctrine as it stands to-day is to be found in those text-books, written by admitted authorities, which have been published in the last twenty or thirty years. It is not suggested that the original observations of scientific workers are to be found in the text-books, except occasionally by way of illustration, but that those laws and theories which are admitted as canonical have been selected by the authorities who write the text-books, and, when so selected,

may be regarded as constituting an accurate statement of the accumulated body of scientific knowledge. Questions which are still being debated are only potentially part of scientific doctrine. It is of no use our trying, here and now, to assess the truth of judgments which other people may make in the future. It is with those laws of science which are not at present the subject of controversy and with its theories that we are to concern ourselves. Scientific doctrine may be dissected as follows:

SCIENTIFIC DOCTRINE
- Laws
  - Descriptive Laws
    - *Factual Laws*
    - *Classificatory Laws*
  - *Quantitative Laws*
- *Theories*

Factual Laws. The laws which have been called factual are those which assert what are commonly known as the facts of science. They are the results of direct observation. Many of them are known to common sense, such as the law that water expands when it freezes. Others are obtained by the splitting of crude common-sense laws into more accurate statements. Common sense tells us that there is such a thing as glass, but science recognises hard glass, soft glass, lead glass, and many subdivisions of each of these classes according to its constituents and to the proportions in which those constituents are present. Scientists have taken particular pains to ensure that their statements of factual laws agree with the observable state of the case: it is on this account that they have admitted as their subject-matter only those sensations about which universal agreement can be obtained. No more thorough scrutiny is given to facts in any branch of human activity than in science. The majority of scientific facts are as certain as the everyday

observations of common sense on which we all act, for the observations are of invariable associations between some of the qualities of things. By whatever form of words we record our observation, we are in effect either stating a law directly or are implying a law. In science we are as careful as it is humanly possible to be to ensure that our statement of a situation as observed is representative of the thing as it is. But the word "true" means "representing the thing as it is". We may therefore conclude that the majority of the factual laws of science are true within ascertainable limits.

It is necessary to qualify our conclusion and to say that the majority rather than all the factual laws of science are true, not only because of the well-known fallibility of human observers, but also because of known but ineradicable imperfections which are inherent in the processes of observation used. We are frequently aware of errors or deficiencies in our instruments which give us distorted or ill-defined results. If no better observations can be obtained we may have to be content with those which are known to be imperfect, such as the images produced by high-powered optical instruments. Any inferences we may draw from such observations will be uncertain to the extent of this imperfection.

Classificatory Laws. Some branches of science, such as zoology, botany, mineralogy and chemistry, consist in large measure of description and classification of the things with which they concern themselves. We have already seen that the statement that a particular thing exists is an assertion that it has certain properties which are in an unvarying relation and is therefore a law. The classifications which these sciences make are also laws in this sense, for they assert that systems of things exist all of which possess certain qualities. Nevertheless, classificatory systems are not usually recognised as expressing laws, and it has sometimes been thought that such branches of science as descriptive zoology and botany assert no laws at all. The usual opinion has been that they simply give definitions of species, genera, classes, kinds, or whatever the technical term may be.

But we have already concluded in our examination of meaning that definition *is* the assertion of the existence of relations. If the relations can be shown, in all probability, to be invariable, the defining relation can be used to assert a scientific law. For instance, a text-book of chemistry may define an "element" as "a substance which has not hitherto been split up into two or more different substances by chemical means". There are substances, in other words, called elements, which possess the property of resistance to certain influences which the chemist can bring to bear upon them. The definition has here been restated in the form of a scientific law, but it is usually called a definition.

In the same way, the definitions of the biological classes can be stated as laws which assert unvarying relations between the properties of the members of the class. If the relations selected are found by experience to be in fact always present, the laws are true, in the sense of true which we have adopted. In the case of the chemical elements, if it is a fact that only those substances which have resisted the attempts of the chemist to decompose them are included in the list of elements, then the classification may be regarded as true.

It must be noticed that all definition is *ad hoc*. The labour of formulating a definition is only undertaken with a particular purpose in view. Definition may be useful in narrowing the scope of an inquiry, or in removing uncertainty or ambiguity. It is of value in argument, to ensure that disputants are concerning themselves with the same subject-matter. It is often required to satisfy the persistent inquiries of a child. Thus, definition is employed in a particular context for a particular purpose, and is, on that account, seldom all-embracing or final. It is always the relevant aspect of the *definiendum* which is stressed.

The definition of "element" is made in the form quoted above for the purpose of elementary instruction, and is employed at a particular "level of reference", a term which will be understood by every teacher. It is now believed that all of the chemical elements can be split up, for instance,

by bombardment with alpha particles or with neutrons. At this level of reference the definition of element would be given in terms of minute structure.

Biological classifications, too, are made strictly for a purpose. They are meant to be useful rather than exhaustive, as can be seen by considering the law which defines the class of mammals. These are defined as warm-blooded animals which possess hair, suckle their young, and have a diaphragm between thorax and abdomen. Custom, as it happens, has decreed that scientific definitions shall be cast in a form in which they are unrecognisable as laws, unless they are translated into quite unfamiliar terms. Biological classification is nevertheless the assertion that certain things have been found to possess invariable qualities. The "law of mammals" can be stated in the form "there are animals which possess the properties of warm-bloodedness, hairiness, lactation and division of the body cavity by a diaphragm: for convenience all these animals will be said to constitute a class, which is a symbolic fiction or part of the machinery of thought: the name reserved for this particular class is the class of mammals". This expanded statement is what the definition means, but we are so familiar with definitions and their purpose that we usually concentrate on the qualities listed and ignore the tacit assertion that an unvarying relation between a set of properties has been observed. If it is the case that there are creatures with the properties mentioned in the definition, it may be said to be true: and indeed definitions must be true if they are to promote the purpose of science. But the defining relations are selected for the purpose of classification. Only those which are relevant to this purpose are included in the definition. There may be other properties common to all mammals which it is not thought necessary to mention. It may be taken for granted that classifications are true in the sense that it is the case that the objects classified do in fact possess the properties named, but the primary question arising out of classifications is not whether they are true, for this is an indispensable condition, but whether they are useful and

fulfil the purpose for which they were made. The successful scientist in the field of classification is he who selects those defining relations which turn out, when submitted to the test of practical application and to the fire of criticism, to be fruitful in ordering the facts of science and to be stimulating to other workers in the same field.

Quantitative Laws. It is not proposed to undertake an analysis of number and measurement in order to estimate the validity of quantitative laws. The use of number and measurement in science does not differ essentially from the similar operations of common sense. It differs only in the care with which these operations are applied and in the ingenuity which is expended on attaining an accuracy which would be useless to the merchant and embarrassing to the technician. In addition, the aid of mathematicians has been enlisted and has resulted, among other things, in the elaboration of a statistical method of great complexity, and of a calculus of probability.

It has already been stated that the quantitative laws of science are not observations, although they are founded on them: they are inferences from observations in all cases. Observations can be true, in the sense of true which we have adopted. Is there any reason for supposing that those inferences from observations which we call quantitative laws are true also? This is the main question of our inquiry and the answer to it is clear. It has already been concluded that the result of deductive inference can be certain, always provided that the premisses from which the deduction is made are true. These premisses are general statements or universals, and can only be arrived at by the process of induction. The question of the truth of quantitative laws therefore depends on the validity of the inductive process.

There is one major induction which is so interwoven into common sense that it is the basis of all human life. It is that because things have in the past persisted in time they will continue to do so in the future. Stones do not vanish into thin air. Night is, in these latitudes, followed by day. A good many of the qualities which things were observed to have

yesterday are found in them again to-day. It is true that there are many changes going on around us, but we find that if no new influences are brought to bear upon things, they do tend to persist unchanged. Our life is conducted on the expectation that the qualities which we observe in objects will be found in them again to-morrow, and most of our expectations are justified. In short, the future, when it becomes the present, does resemble the past in many respects. But it cannot be pretended that this commonplace induction reveals the nature of science. It is the basis of all conduct and the common ground of all human experience. To elevate it to the status of a fundamental principle of science is to overlook the fact that it is not specifically scientific at all. It is shared by commerce, politics, art, religion and ethics. The principle has been called the Law of the Uniformity of Nature. It has been invoked by writers on scientific method as the fundamental scientific intuition, but the claim amounts to no more than the assertion that science is a human activity and is concerned with nature as it is. It contributes nothing to the solution of the problem of the truth of scientific laws.

In order to discover in what degree the quantitative laws of science may be regarded as true, it will be best to consider a simple example of such laws. Galileo's Law of Falling Bodies may be stated in the form "the distance fallen by a body is directly proportional to the square of the time for which the body is falling"; or in symbols:

$$S \propto T^2.$$

This law or any other quantitative law may be assailed in two ways. First, how accurately do the observations fit the quantitative expression of the law? Secondly, even if the law states an invariable relation for the observed cases, how do we know that it will fit those cases which it claims to cover, but which have not been observed? These two questions are quite distinct, but they must both be answered if we are to be able to describe the quantitative laws of science as true. Consider our example again. Suppose that we conduct a series of experiments to establish the law of falling bodies

with the most up-to-date equipment and with every precaution of which we can think. We write down the times during which the body is observed to fall, and also the distances fallen. Our recorded measurements are not whole numbers. The more accurate the instruments we use, the more decimal places we are forced to employ in our statements of the measurements of time and distance. Further, because we find that we cannot repeat an experiment exactly, we repeat it as nearly as we can, and include in our column of results not single measurements of time and distance, but averages or statistical mean values of the recorded quantities. These are not observations; they are mathematical abstractions. The results of mathematical computation are often exact, but measurements in real life are never exact, and so our observations are approximate only. They approach more and more closely to "true" measurements as our skill in measuring increases.

Suppose that a certain time interval is to be measured. I have an apparatus which I have reason to believe can, if suitably operated, measure time intervals with an accuracy of one-hundredth of a second. No better apparatus is known to me. I make my measurement with all due care, and pronounce the time interval in question to be thirty-five hundredths of a second. This result must be regarded as true for practical purposes, unless it can be shown that I have committed an avoidable error in my use of the apparatus or unless a machine is brought to my notice which will measure intervals of time smaller than one-hundredth of a second. It is of no use to argue that the time interval in question must have had a real value, which may be anywhere between sixty-nine two-hundredths and seventy-one two-hundredths of a second. In the circumstances such knowledge is unattainable, and there is no reason to suppose that any absolute accuracy of measurement will ever be within our power. If then they are the best available, scientific measurements possess limited or approximate truth, for we can often state between what limits the "true" measurement must lie. We can never measure with an accuracy greater than that

imposed by the inherent limitations of our measuring devices. To talk of the absolute accuracy of scientific measurements is to talk nonsense.

The second question has already been debated. It is the question whether inductions about observed relations can be regarded as true. The relations discussed in physics are considered to be so impersonal, so remote from the vagaries of human control, that a few observations are taken as a fair sample of all possible observations, and the law which is found to express a relation between the observed facts is assumed to hold for those other cases which it is not thought necessary to investigate. Such inductions are made confidently because they are found by experience to enable us to predict events. If a law of physics is doubted, the work on which it was based can be repeated, and the law can be either confirmed, modified, or rejected. We have complete confidence in the inductions of physics, when once they have been tested by men whose work is known to be of good quality, but our confidence in them is no greater than that of the common man who assumes that what looks and tastes like bread is a foodstuff and not a poison. The inductions of physics are sufficiently certain for its successful growth, but they are not absolute truths. They are probabilities, approaching but never overtaking certainty. The laws of science venture to offer guidance for future experiments, but although physicists strongly suspect that at any rate the near future will resemble the immediate past, neither they or anyone else can have any final assurance that it will do so.

It has been said that a very high degree of probability can be attained by the methods of physics, and indeed, many of its laws are of the highest precision, but it is not so with all of them, and in some branches of science, such as biology, the probability of some of the laws is quite low. This is because of the difficulty of applying the quantitative method to living things, and accounts for the fact that physics, which may here be taken to include astronomy and chemistry, contains many more quantitative laws than the biological

sciences, which are largely descriptive; but biologists are fully aware of the importance of measurement for the progress of their branch of science, and are continually looking for means of applying quantitative methods. Biochemistry and biophysics nowadays have separate text-books of their own.

We must now see, by way of example, to what extent Galileo's Law of Falling Bodies and Boyle's Law can be said to be probable. The measurements of time and space required for testing Galileo's Law can be made exact enough to give a very high degree of probability, but only over a comparatively restricted range. Is the law to be regarded as true for all values of "T"? We do not encounter bodies falling freely in a vacuum under gravity for periods of hours or days, and therefore we have no means of knowing whether the law is true or not in such circumstances. This ignorance is, of course, quite unimportant for practical purposes. and does not invalidate the law so far as physics is concerned. The induction, which has been made from limited terrestrial data, has been applied with marked success to the solar system, and is invested with a very high degree of probability.

That Boyle's Law is only an approximation to the quantitative expression of an invariable relation was soon discovered, and the deviations from the law have been very fully investigated. In its original form it is a law of restricted scope, but at very low pressures the observational evidence upon which it is based shows that it has a high probability. Attempts have been made with considerable success to formulate new gas laws to cover the circumstances to which Boyle's Law does not apply. The original law has had to be split up into parts, one part being for use at low pressures and another part being for use at higher pressures, but the high pressure law is the more fundamental, for Boyle's original law is found to be a special case of it, when such disturbing factors as the mutual attractions and actual volumes of the molecules happen to become immeasurably small.

Any quantitative law of science must inevitably be founded on observation and must also be a generalization from particular instances. Several such laws have now been known for over a hundred years. Great reliance is placed upon them because the observed quantities which fit in with one of these laws can also be calculated from it, and no discrepant instances have been discovered. Such laws possess a high degree of probability. Many less reliable quantitative laws are also known to science, some of which are recognised as being unsatisfactory and are in process of modification. We cannot say more than that some of the quantitative laws of science possess a very high degree of probability, approaching practical certainty. Thus "truth" in science is never absolute: it is probability, that is, it is a measure of the amount of knowledge which we have about a situation or an event in nature. This meaning is quite definite and is adopted naturally by scientists as they learn their craft. Other meanings of the word "truth" are ignored or are kept for those occasions when the scientist is not thinking scientifically, as in ordinary conversation or when he is in church. "Truth" in the religious sense is "the object of religious faith", but it is in no way connected with scientific truth. It is a pity that there is only one word to symbolize such different ideas, and it must be admitted that religion was first in the field.

Sometimes a law is spoken of in a derogatory way as "empirical". This word should mean "based on observation and experiment", which is exactly what is required of a law in science; but the custom has grown up of regarding empirical laws as somehow less important and less true than some others which are not called empirical. Unfortunately scientific writers have spoiled the use of this word, which aptly describes the procedure by which the data for the laws of science are obtained. What is meant by those who use the word empirical in this slighting way is that some laws, the result of observation and experiment, have been very thoroughly tested and that, because of their relations to other laws and theories, they have been found to explain

some portion of experience in a satisfactory manner: whereas certain other laws, also the result of observation and experiment, appear as yet to be unrelated to known phenomena and seem to lack antecedents. These last are thought to be the result of mere experience, and have failed to give the required psychological satisfaction demanded of scientific explanation. Thus "empirical" has come to mean "not yet having been shown to be related to the accepted body of scientific doctrine". Such laws are not necessarily less probable or less true than others, except in so far as their place in the framework of science has not yet been found.

Theories. It has been said that theories are attempts to explain the laws of science. They give an imaginative account of the unobservable details of natural processes by making use of an analogy to describe the unknown in terms of the known. A theory is acceptable, to some scientists, at least, if it can be shown that laws already substantiated can be deduced from it, and if it possesses the power of prediction, in the sense that it suggests new laws which are later found to be in accordance with observation. In addition it must somehow illuminate the whole subject with which the group of laws in question deals. It must promote the scientist's understanding of nature. The test of a theory is pragmatic, for it depends upon the practical consequences of that theory. If it is successful in fulfilling the purpose for which it was constructed, it is embodied in scientific doctrine, and it will appear in some at least of the text books. But to fulfil a practical purpose is not to be true, except in a very unusual sense. Some of the Pragmatists hold that a statement or a belief is true if it has practical consequences: if it has no practical consequences it is either false or meaningless, but we cannot subscribe to this definition of truth. The writings in which Pragmatism is embodied are quite admirable for their attacks on the abstractions which are so frequently mistaken for things and for their insistence on shunning an excessive intellectualism in favour of something more in touch with human life. Pragmatism is, in fact, an attitude towards philosophical problems rather

than an attempt to solve them. It provides us with no acceptable criterion of truth.

It will be as well at this point to indicate the meaning which is here attached to the word "observable". Speaking strictly, only sensations are observable, but we usually assume that there is an external object which somehow provokes or causes a sensation, the existence of the object being an inference from that of the sensation. Common sense takes these objects of sense perception for granted, ignoring the philosophical point that they are in fact inferences from sensations, and it is these objects of sense perception which are here to be understood as observable. An object possessing a smell, or a taste, is observable. So is an object like a tuning fork, which produces a sound. A tuning fork is, of course, also observable by the tactile sense and by sight. When reinforced by touch, the sense of sight provides very convincing evidence to common sense of the existence of objects, and because the telescope and microscope can be used to give magnified images of certain objects which can also be observed by touch and sight without instrumental aid, small objects like bacteria and remote objects like Saturn's rings, although not directly observable, are so little removed from direct observation as to be classed as observable. The sense of sight is found to be trustworthy enough in practice, if certain precautions against deception are taken. Atoms cannot be seen as individuals, but are believed in by reason of a chain of inferences from observations. When we see individual flashes of light in a spinthariscope, we are not seeing individual alpha particles, but we infer their existence. Similarly with cloud chambers, Geiger counters and Millikan's oil drops. We infer the existence of unobservable particles from observable events. A theory is necessary to allow us to arrive at the notion of these particles, which must be regarded as symbolic fictions. Atoms and electrons are constituents of the machinery of thought by means of which the scientist builds his picture of what the small scale or remote processes of nature would be like, if they were observable.

We will admit, then, that the value of a scientific theory depends upon its practical consequences, but we deny that there is any guarantee of truth concealed in the admission. The reason for taking up this position is not difficult to discover. A theory is an imaginative construction. It postulates the existence of something which is unobservable and ventures to suggest what the unknown is like. Atoms, molecules, electrons and light-quanta are fictions. Such things may exist, but there is at present no way of telling whether they exist or not, and if they do exist and can be made observable they cease to be fictions. They at once become the subject-matter of laws, not of theories. To argue whether a fiction can be true or not is to beat the air. Fictions can be useful, or suggestive, or psychologically satisfying, but they cannot be true, for they are only part of the machinery of thinking. It is thoughts about things that can be true or false. A statement is true when the form of words used does actually refer to the event intended. By an event is meant something that can be observed; but atoms cannot be observed. Their existence is inferential only. Hence, in the strict sense in which the word true is being used here, a theory may be regarded as adequate, or useful, or fertile, but it cannot be true. The question, "Are theories true?" is wrongly conceived.

We are now in a position to summarise our answer to the question "Is science true?" By science is meant the contents of those textbooks of the special sciences which have been published in the last twenty or thirty years, together with those writings which are to be found in the periodical literature of each branch of science. This vast mass of material contains laws and theories. Three kinds of laws have been distinguished. Factual laws are the direct records of observations, and many of them are true in the sense that they are carefully worded statements describing sensations about which universal agreement is possible.

Classificatory laws are mostly true because universal agreement can be obtained as to the existence of the relations which they describe. But classification involves the selection

of relations about the truth of which there is seldom any doubt, the chief concern of the scientist being that the relations selected should be the best for his purpose. He asks not so much "Are classificatory laws true?", for this is usually well established, but "Are they useful to him?"

Quantitative laws are constructed with the utmost care, but they are inductions and may therefore be of any degree of probability. Many of the well-known quantitative laws of science have a high degree of probability, amounting to practical certainty.

Theories are not laws. They are attempts to explain laws, or systems of laws, by means of analogy. The question of their truth does not arise. Some theories have proved to be both acceptable and stimulating to scientists: they have assisted in the expansion of the domain of science, and have justified their formulation by fulfilling the purpose of their makers.

CHAPTER IV

EDUCATION

The Task of Education. The great need to-day is for improvement in human relations. We cannot make full use of our faculties unless we can agree to live together without intermittent attempts to exterminate one another in war. The best hope of bringing about the desired change seems to be in the education of young people, for it is unlikely that those of us who are adult can be persuaded to alter our mode of thought with sufficient conviction to translate it into action. It is fairly well agreed that an educated person should have a knowledge both of people and of things: he must possess common sense and *savoir faire,* so that he can satisfy his reasonable aspirations without being hoodwinked or victimised; he should develop the habit of applying a moral code which clearly indicates to him what is accepted by society as right conduct; he should acquire reasonable proficiency in distinguishing truth from falsehood and nonsense from either; and he should have some knowledge of the kinds of experience which others have found to lead to aesthetic satisfaction. Education for taste is an indispensable ingredient in building the kind of society which most educators would like to see. Cultivated people, it is said, use a certain precision of speech; they have an acquaintance with many arts and skills; their manners are so adjusted as to give pleasure rather than pain or annoyance to others; they are acquainted with the more important trends in the history of human thought; they are sensitive to the finer shades of conduct; and they are duly appreciative of the achievements and opinions of those in walks of life other than their own. It is inexcusable if those who have had opportunities to attain such standards should fail to

maintain them, and a beginning has been made to ensure that all children are brought within the range of those influences which may reasonably be expected to lead in the direction of the ideal.

To succeed in these aims would be the crowning achievement of education, but there is much spade-work to be done before the efflorescence of polite living can shed its mellow influence over the whole of human society. Let it be assumed that the system of education adopted will suffice in most cases to restrain the fundamental passions of cupidity, ambition and sex from producing those disruptive consequences which so often follow when the passions are given free play. Let it be assumed that the environment of school and home will be such as to furnish young people with a good measure of common sense, an enlightened and many-sided common sense which will allow a member of a community to appreciate and to exercise sufficient control over the situations he encounters for him to compete on equal terms with others, without his becoming a charge on society or an embarrassment to his family. Then, in view of the changes which have taken place recently in our mode of living and in expectation of more changes to come, we ought to consider whether the resources at our disposal are being used judiciously, or whether we are, perhaps, providing a mental diet which is neither sufficiently digestible nor conspicuously nutritious.

For the ordinary interchange of ideas and goods the minimum demands of society have long been the practice of reading, writing and arithmetic. Whatever standard is set for the finished article at the end of his span of formal education, there is no doubt, in the light of subsequent events, of the wisdom of those who ordained that all children should be trained in the three R's. To be able to read public notices, to fill in the forms provided by an industrious civil service, and to be able to compute one's indebtedness to the State or to others, are indispensable qualifications for modern life. To these three essentials of education a fourth should be added. The very detailed investigations of nature

that have been undertaken during the last three hundred years have put many ingenious devices into our hands, devices whose uses are soon learned but whose limitations are not obvious. The mysteries of nature and the mysteries of mechanism surround us; yet, although many mysteries are still unsolved, a consistent account can now be given of the place of man in nature, of the measure of control which he possesses or is likely to possess over his environment, and of the needs and working of his own body. It is the careful inquiry of the men of science that has brought this change about and has created the necessity that those who live in a world where labour has been lightened by knowledge and invention should at least possess some of the knowledge and understand some of the inventions. This need for an introduction to the results of scientific research provides us with a fourth R. Taking part of a phrase as indicative of the whole and for the sake of alliteration, we may say that the essential groundwork of a curriculum for all consists of reading, writing, arithmetic and some knowledge of the results of scientific research, the fourth R being more commonly known as General Science. All are means to living in the modern world. A very little knowledge of science will be sufficient to resolve some of the difficulties with which the average man or woman is confronted to-day. The behaviour of various fuels; the differences between alternating and direct current; the uses of conductors and insulators; food values; the efficaciousness of various drugs; the effect of alcohol on the human organism; these and many other normally obscure topics would be illuminated by only a slight acquaintance with the subject.

The Norwood Report (1941)[1] says: "We take it as self-evident that, if education is to fit pupils to live in the modern world and to gain acquaintance with the main departments of human thought, a study of Natural Science should find a place in the education of all pupils. But this does not mean that pupils with little capacity or interest in Natural Science

[1] *Curriculum and Examinations in Secondary Schools*, p. 108 (H.M.S.O. 1941).

should necessarily take it throughout the Main school, or that the time given to it or the content of the course should be the same for all pupils in the same school; allowance must be made for strongly developed interest and abilities in other fields, and equally for interest in Natural Science and the probable needs of a future career. . . . We would suggest that for the first stage the course in all schools and for all pupils should consist of a general approach to the main fields of Natural Science. This kind of approach has come to be known as 'General Science'. General Science is the name given here to an elementary course of study of Natural Science for which the subject-matter, related wherever practicable to the everyday experience of pupils, is drawn from the whole field of Natural Science and treated as a coherent whole, so that the question of the traditional division into separate Science subjects such as Physics, Chemistry, Biology, Astronomy and Geology does not arise. The course of study, by the scope and treatment of its subject-matter, is designed to give pupils, among other things, some knowledge of natural laws and their applications, some acquaintance with scientific methods of thought and investigation and some appreciation of the influence of scientific thought and achievement on human lives. We would advocate the adoption of some form of General Science as the most suitable introductory course."

No future citizen should be left in ignorance of the pattern and powers of nature now that so much is known. No child should be denied a chance to see the picture of his material setting now that it has been at least partially illuminated. In these times, to withhold the opportunity of an acquaintance with elementary science from any young person who might become interested in it is to cheat the individual and to run the risk of weakening the community as a whole. It is necessary that young people should know something of what science has done, what it can now do, and what it may reasonably be expected to do in the near future.

It is common knowledge that general science has now been taught in schools for a number of years, but neither the

syllabus nor the order of presentation of the topics included in it has been agreed upon, much being left at present to the individual teacher. Already, textbooks have been written which have become standard for a large number of schools, and we may expect that, as experience grows and new aspects of science come to the fore, there will be new textbooks which are suited to the educational needs of the time. It is a sound principle of education to proceed from the well-known to the less well-known: each fresh topic should be introduced and illustrated by references to such familiar objects as a watch, an electric bell, a radio set, or the human body. Consider the watch from the point of view of the amount of illustrative material it contains. Its purpose is to indicate equal intervals of time: this may lead to a talk about time, which requires some knowledge of the solar system. The balance-wheel serves to introduce the principle of isochronism, with a reference to the simple pendulum, elasticity and expansion. The properties of the metals used in watch-making provide more material; so do the properties of glass, jewels and, perhaps, luminous paint. The escapement suggests the principle of the lever. The mainspring and train of cog-wheels lead to the conception of potential energy and the transmission of motion. With young pupils, theoretical ideas must constantly be related to objects of their experience. It is not suggested that the object lesson should be employed as a substitute for formal science teaching, but frequent references to familiar applications of theoretical principles can be used both to maintain the interest of pupils and to emphasise the importance of the quantitative method.

Having arrived at a formula for the minimum educational requirements of all children, we may turn to the question of the next step to be taken. If by education is meant the provision of an environment which will promote the development of the faculties of the individual in such a way as to satisfy both his psychological needs and the needs of the society of which he is a member, it is necessary that we should have clear ideas about what these needs are. We must know the characteristics of the material that is to be educated;

and we must be able to foresee the requirements of the society which this material will ultimately form, for society is organic; it is a wise man who can correctly foretell the trend of its development.

The needs of the individual. What kind of persons are there in the world? By the end of a long and varied life the majority of men could give a reasonably comprehensive answer to this question, but it is far from easy for young people to do so, who have as yet formed only a small circle of acquaintance, or have been too busy adjusting themselves to their material environment to have given much reflective thought to the characteristics of their fellows. It seems desirable that an inquiry in any way connected with education should be based on knowledge of the human material that is to undergo the proposed transformation, although such knowledge as there is must be regarded as provisional, for on such an intangible subject there is never likely to be complete unanimity among the experts who have devoted themselves to the classification of human types. What is called knowledge to-day is but the starting point for the orthodoxy of to-morrow.

Everyone is aware that a great diversity of types exists among human beings. There are recluses and men of action, generous people who will give away their last penny in order to help their fellows, and drivers of bargains so hard that our admiration for their success is tempered by a shrinking fear that we might one day find ourselves in their clutches. Such popular classifications are useful at times, but they are not comprehensive enough for our present purpose of examining the place which science should have in the education of the school population of a modern state.

It would not be profitable to review in historical order the works of those writers who have contributed to the various classifications of the human character, nor could the task be carried out within a convenient compass. The minds of great men are known to us in some measure by the record of their deeds or through the good offices of their biographers. Many great men have possessed powers of expression and

we can estimate the quality of their minds by an inspection of their writings or their works of art. Scientific writers in particular have left detailed records of the methods by which their conclusions were reached, a circumstance of great importance for the understanding of their mental outlook. The earlier classifications of mental types have been improved upon and amplified. The latest theories are not yet old enough to have acquired the stability which is only reached through the perspective of time, but, fortunately, a classification of mental types of over twenty years' standing is to hand; its merits have been widely acknowledged; and, although psychologists are not satisfied that the last word on the subject has been said by Jung[1], his views are sufficiently penetrating and authoritative to serve the purpose of reminding readers of the different types of mind and disposition which they may expect to encounter in their fellow men.

Jung's first classification is into the two types which he calls the Introversion Type and the Extraversion Type. These he calls the general attitude types, for they are distinguished by their attitude to the object of their attention. That we are influenced by the data which reach us from outside ourselves is obvious, but we may react to these data in two quite distinct ways. Some people make a direct response to their surroundings. They do what the majority do, they are eager to meet fresh people and to see the latest sights, they like to be in the fashion and to experience the latest thrill. These extraverts tend to conform to their environment uncritically, thinking and acting in response to it. Other people behave in a different way. An event outside them is considered critically before an active response is made. If they go to Blackpool at all, it is to observe the crowd rather than to mingle with it. They tend to interpose an intellectual action between the stimulus and their response to it. They first consider the effect of the stimulus on them as subject, after which such conduct as is dictated by their psychic mechanism will follow. Often, no action is taken,

[1] Jung, G. C.: *Psychological Types* (Kegan Paul, 1923).

for the introvert finds satisfaction in assessing the value of the external event or in following its implications in relation to himself, rather than in participating with others in the event.

These are the broad fundamental divisions of personality made by Jung, and it is clear from his writings that he considers every individual to possess both mechanisms, although one or the other may predominate. The extraverted type is not extraverted in all his actions at all times; sometimes his actions are of the opposite character, but there will be a leaning towards one side or the other; a majority of actions will perhaps be of a certain kind, thus indicating a bias in outlook or behaviour which is clearly recognisable as one of a pair of opposites. It may be that the frequency with which an action of a certain kind is performed will give an observer the required indication, or it may be that the more important or striking actions performed during a man's life, those outstanding actions which make or mar a career, the vital decision which may so profoundly affect both private lives and public policy, will give the clue which is required for the diagnosis of the type to which a person belongs. Perhaps the majority of us are too colourless, too much mixtures or both types, for indisputable insertion into one of Jung's classes; yet the better a person is known and the more intimate our relations are with him, the greater will be the probability that a fair estimate of the trend and tenor of his character can be safely and correctly made. The label "mainly introvert" or "mainly extravert" can then be correctly fixed. We cannot do better than quote Jung's own words:

> "The opposite attitudes are merely opposite mechanisms —every human being possesses both as an expression of his natural life rhythm. The complicated external conditions under which we live, as well as the presumably even more complex conditions of our individual psychic disposition, seldom permit a completely undisturbed flow of our psychic activity. Outer circumstances and

inner disposition frequently favour the one mechanism and restrict or hinder the other; whereby a predominance of one mechanism naturally arises. If this condition becomes in any way chronic a *type* is produced, namely an habitual attitude, in which the one mechanism permanently dominates; not, of course, that the other can ever be completely suppressed, inasmuch as it is also an integral factor in psychic activity. Hence there can never occur a pure type in the sense that he is entirely possessed of the one mechanism with a complete atrophy of the other. A typical attitude always signifies the merely relative predominance of one mechanism".[1]

Jung found that this twofold classification into attitude types was widely and gratefully accepted. He also saw that there are certain broad ways in which the personality operates, called by him "functions", which would serve to give a more detailed, and therefore more valuable classification of the different ways in which people adapt themselves to life. These he called function-types, his primary division being that of Rational and Irrational. This scheme gives four main classes of personality:

(1) Extravert Rational
(2) Extravert Irrational
(3) Introvert Rational
(4) Introvert Irrational

Jung's use of the words rational and irrational is not hard to grasp. The rational is that which is in accordance with reason. The rational functions are *thinking* and *feeling*, so long as these are influenced by reflection and result in a judgment. Non-reflective mental operations, such as that which gives rise to an automatic response to an inquiry after our health, do not count as thinking in this sense. By the term irrational Jung means not something which is contrary to reason, but that which is outside and apart

[1] Op. cit.: Introduction, p. 12.

from reason, such as the reply "Very well, thank you", when we have a slight pain or indisposition, but know very well that an account of our symptoms is not required. The irrational functions are termed *sensation* and *intuition.* There are thus four function-types, each of which may be extraverted or introverted, giving a total of eight categories into which it may be possible to classify the persons of our acquaintance; but it must be remembered that a type can only be recognised when a particular characteristic is so prominent as to provide the required clue. Further, it is the attitude of consciousness which is most likely to be open to the inspection of the layman. The corresponding characteristics of the unconscious which are attributed by Jung to the eight types had better be left to the full-time student of psychology. The eight types may be tabulated thus:

$$\text{Extravert}\begin{cases}\text{Rational} & \begin{cases}\text{Thinking}\\ \text{Feeling}\end{cases}\\ \text{Irrational} & \begin{cases}\text{Sensation}\\ \text{Intuition}\end{cases}\end{cases}$$

$$\text{Introvert}\begin{cases}\text{Rational} & \begin{cases}\text{Thinking}\\ \text{Feeling}\end{cases}\\ \text{Irrational} & \begin{cases}\text{Sensation}\\ \text{Intuition}\end{cases}\end{cases}$$

The chief characteristics of these eight types will now be briefly described, so that a perspective view of the composition of human society can be gained in terms of them.

(1) *Extravert Thinking Type.* When the life of a person is mainly ruled by reflective thinking in such a way that careful thought precedes all or nearly all of his more important actions and when the majority of his motives are intellectually considered, he may be said to be of the thinking type. If it is his habit to order his life in accordance with intellectual conclusions which have been derived from objective data, that is, from things or ideas which come from outside himself, he is of the extraverted thinking type.

In extreme examples of the type he will have repressed the feeling function to such an extent that he has no appreciation of art and is largely friendless. The irrational functions which lead to religious experience are also repressed so that he seems to be a cold, forbidding person who shuts himself off from his kind. Reason is held to be more important than the person; the person must conform to reason and is dominated by it. The other functions, feeling, sensation and intuition, are pushed into the background and are allowed only slight influence. The type consists mainly of men, who are much more given to thinking than women. Many scientists approach this type.

(2) *Introvert Thinking Type.* The subjective factor is dominant in introverted thinking. The judgment is not swayed primarily by a consideration of whether its conclusion fits the facts, which are external, but by the acceptability to the thinker of the theoretical framework which the facts suggest. The process is not one of concrete—judgment—concrete, which is the process of science, but of concrete—judgment—subjective content. Thus, introverted thinking can lead to new views about concrete situations, but it is not particularly concerned with the verification of such views. It asks questions and formulates theories, produces speculative generalisations and analogies, but facts are regarded as being of secondary importance. It is of the type which searches for reality. The facts are only the framework of the idea, which is all important. The creative power of introverted thinking is shown by the number and variety of theoretical systems which are contained in that part of human thought that has been recorded. Many of these systems are speculative or conjectural. They are founded not on fact, but on fancy. Accordingly most philosophers belong to the introverted thinking type. The reason why it is unlikely that there will ever be universal agreement about philosophical systems is that the subjective process is used in their construction.

Nevertheless, the qualities of the introverted thinker are necessary for the production of scientific theories, which

are imaginative constructions. Since the author of a theory may be part introvert only, he may have the capacity in addition of putting this theory to the test of experiment. If he does so he is not an extreme example of the introverted type, in which many scientists must undoubtedly be included. Jung stresses again and again that his types are extremes. There is so much common ground between the types, and so much of our behaviour is dictated by outside circumstances, that great caution is necessary in drawing conclusions from the actions of a person who has been only superficially observed.

(3) *Extravert Feeling Type.* In this type the external object determines the kind of feeling. The feeling agrees with objective values. It is found that actions are subordinated to a scheme of traditionally or socially correct conduct. A judgment of what is right or fitting conduct is made because the situation is *felt* to demand it. Extraverted feeling of this kind is responsible for a part of the crowds which attend theatres, concerts, churches, lectures, political meetings and public entertainments. Fashions in clothes and in philanthropic work are due to the same cause. The type is frequently to be found among women, many of whom are said to have a *feeling* for dress or for a certain standard of social conduct. It is the agreeable feeling-situation, more than anything else, that makes the tea-party so popular a diversion. Examples of the extraverted feeling type are also to be found among men; it is this psychic function which is responsible for a good deal of social harmony.

(4) *Introvert Feeling Type.* When a feeling which is actively directed, not merely passively endured, is turned towards the subject, the function of feeling is introverted. For a person of this type the important thing is the feeling evoked by the relation of the object—which is usually abstract, such as God or beauty—to the subject. If this condition predominates over other psychological functions, the person, who is usually a woman, is of the introverted feeling type. Owing to the difficulty of expressing feelings in words,

it is hard to describe the content of the consciousness of this type, but the mystic and ecstatic are examples. Less extreme cases are silent, inaccessible, perhaps melancholic, and hard to understand. They neither shine in the company of their fellows nor reveal themselves in friendship. They are often quiet, serene and devoted to their children.

The four types discussed above are called rational because they make use of reason, where reason is to be understood as a principle which is employed to influence thought or feeling. When the operation of no such principle can be detected, the psychic situation may be called irrational and, according to Jung, four more types are to be discovered.

(5) *Extravert Sensation Type.* In this type, only concrete, sensuously perceived objects or processes produce sensations and it is such objects or processes which are sought. The rational functions are subordinated to sensation and are made to serve its end, which end is concrete enjoyment. The type is commonest among men, in fact the majority of men conform to it at one time or another. *L'homme moyen sensuel*, fond of food, drink and entertainment, is a very ordinary sort of person, but he may possess considerable refinement, being both companionable and possessing good taste.

(6) *Introvert Sensation Type.* Sensation may be regarded as conscious perception, and perception can only occur when there are both a perceiving subject and an object which is perceived. In the introverted sensation type the nature of the perception is largely controlled by the subject. As an instance of this situation, consider the case of several painters who all set out to reproduce the same scene as faithfully as they can. It will be found that the paintings will differ, not only because of differences of ability, but also because the painters perceive differently. Their subjective sensations are different. It is when this function predominates that the introverted sensation type appears. As the intensity of the subjective sensation cannot be foretold and bears no relation to the intensity of the outside

stimulus, it is controlled neither by reason nor by feeling and is classed as irrational. This type is most obvious in creative artists.

(7) *Extravert Intuition Type.* Since intuition may be regarded as unconscious perception, it is far from easy to describe its nature. In the extraverted attitude the unconscious perception is directed towards outside objects. The intuitive function thus somehow discerns relationships between external objects which could hardly be arrived at by reason, feeling or sensation. Persons of this kind are not strikingly interested in sensation, indeed, sensation is repressed, but they are always looking for possibilities in an external situation, with a keen eye for those things which give promise of future development. The intuitive extravert initiates and promotes enterprises of all kinds and is often very well paid by society as long as he is successful. But the very nature of his activity is to pass on to the exploration of new situations, so that he frequently fails to reap the reward of his enterprise. Merchants, speculators, contractors, agents and politicians are of this type; many women also are to be included in it, operating in the social sphere rather than in that of business. They are quick to seize social opportunity and to establish contact with that which will promote their ambition.

(8) *Introvert Intuition Type.* In this type the attention is directed towards what may be called inner objects which have a psychological reality corresponding to the concrete reality of outer objects. Since subjective images are inaccessible to an outside observer, persons of this type have difficulty in expressing their experiences in terms which are readily understood and are particularly likely to be misjudged by extraverts. The introverted intuitive is aloof from his fellows and out of touch with them, as he is concerned with the development of his subjective images. His interest may take an ethical turn, in which case he may become a religious mystic. Although seldom influential in the practical sphere in their own time, it is sometimes these visionaries who have given the trend to the development of

human societies. The novelist Emily Brontë and the poet and painter William Blake are examples.

The recognition of these eight types as the extremes to which the individuals comprising a society may tend at once raises questions for those whose duty it is to determine the kind of education that is to be given to children. To what extent is the personality of the child *tabula rasa* upon which a particular pattern conforming to one of the eight types can be inscribed? Is every mind potentially of every type, or is the character predetermined? If educational environment can influence development towards one type or another, how far can this process be carried? To what extent would it be desirable to do so? Most important of all, what proportions of the different types are required for society as it is now constituted, or as it will probably be constituted in the near future, assuming, as we safely may, that all types have a contribution to make in a civilised state? Probably these questions are unanswerable with any degree of exactness, but perhaps enlightened opinion can give an answer to some of them that will serve as a practical guide, if only as the starting-point of an endeavour to improve the relations between human societies.

There is little doubt in which of Jung's eight classes the majority of scientists should be placed. All are of the thinking type and the majority are extravert, for much of science is concerned with concrete things. Some have a strain of introversion which may be very marked and may lead to the construction of speculative systems, but the speculations must be disciplined and guided by the facts of observation.

In so far as a child is extravert, there is not much difficulty in interesting him in elementary science because of this concreteness and because of the opportunity for the handling of apparatus, which appeals to most children, although they are not all very good at it. If it is concluded that it is desirable to increase the number of scientists in a community, ways must be found of strengthening and developing any tendency to extravert thinking that may be present in

that part of the child population which is of a plastic and undecided character.

Quite apart from that fraction of the population who naturally turn to science as a career, there are many persons of good ability who are capable of understanding what the scientists have done and how they have done it. These are the people who are likely to assume positions of authority; they should be given the opportunity, during their period of formal education, of following the main lines of development of scientific thought, although the subject will doubtless prove to be distasteful to some of them. It is probably true to say that those who are in a position to control national policies are frequently ignorant of the powers that have been put into their hands by the discoveries of science; those who administer the details of our existence are guided by what has been rather than by what can be; and the ordinary run of citizen is hardly less superstitious about matters of health and the future course of events than his predecessors of the remote past.

Jung's eight types are admittedly extremes. Not many individuals can be classified with certainty under them, but how many of us are able to lead our lives entirely according to our bent? We choose a trade or profession and become shackled to it by economic chains. A person of the thinking type may be forced to earn a living by means of some repetitive mechanical process, while one of the sensation or intuitive type may find that he must continually think in order to live. Natural introverts find themselves making public speeches and the gay extravert finds himself hampered in his search for sensation by lack of means. All this is perhaps inevitable, and adds greatly to the spice of life. We try to organise our life along lines that will satisfy our own natural propensities, conforming as far as need be to the impact of circumstances upon us. This is sometimes apparent among children of school age, in whom the characteristics of the eight types often stand revealed. Examples of the thinking type, if furnished with ability, are the schoolmaster's pets. They learn easily and appear

to like doing so. The remainder take to book-learning for reasons of ambition, of for fear that a worse thing should befall them, or not at all. It is often remarked that such-and-sueh a suceessful man did not shine at school. Why should he? It was not that he could neither understand nor remember the work that was set him, but simply that he was not interested in it and, in consequenee, he evaded it. It is even arguable that these aets of evasion, whieh are really little more than a getting of one's own way, are invaluable as praetiee for comparable aetions in adult life. To get one's own way, to shun subservience, is hailed as a sign of charaeter and is duly applauded as at least the prerequisite of sueeess.

It seems probable that education ean to some extent *make* types, or, rather, it can direet the human material into a particular type-channel. This may be done by the presentation of the ehosen type as an ideal, with expositions of the advantages in material or emotional satisfaetion to be derived from eonformity to it, and by the example set by teaehers in their own mode of living. It is not thought that it should be the aim of education to produee extreme examples of any one type, in whieh a certain mode of behaviour dominates the personality almost to the exelusion of all others, but that the potentialities of each child should be free to expand upon lines whieh are satisfaetory both to the individual and to society.

The aims of edueation have been variously set out, but the main departments may be enumerated thus:

(1) Edueation in values. A standard of moral values must be presented to ehildren. Whatever may be done or left undone in the child's home, reinforeement in the sehool is desirable. The same eonsiderations apply to the presentation of aesthetie values.

(2) Edueation in religion. This is eommonly linked with ethieal teaehing, but is theoretically separable from it.

(3) Education in eharaeter. Two aspects of charaeter in particular are of importanee. One is persistence: the ability to earry a task through to eompletion. The other is that

kind of self-control which confers the ability to sacrifice an immediate and fleeting pleasure for a more remote but lasting satisfaction.

(4) Physical education.

(5) Education in social living. This includes much of the formal instruction which is given to children.

(6) Education for a trade or profession. This is vocational or technical education and must be in the hands of specialists.

Science is concerned with the last two of these: general science as a fourth R, and a detailed knowledge of particular sciences to provide for the increasing demands of industry. It is worth noting that in recent years the quantitative method of science has been employed in solving quite general problems. Under the name of *operational research*, this application of science promises well for the future and may provide an answer to many hitherto intractable problems.

Looking at the broadest aspect of human needs, it seems that the ultimate aim of educators should be twofold: to increase the proportion of persons of good will in all communities, and, at the same time, to provide for the satisfaction of the natural propensities of the individual. Only thus can the comity of nations be attained. It is the work of the humanists that is required here, but, where conflict arises, it is more likely that a peaceful solution will be found among Jung's rational types than among the irrational. Any educational influence which can be shown to be effective in steering the young towards the rational should be encouraged. As always in education, when it has been decided what it is that should be done, the problem of the means to be employed remains, and, as always, the quality of the human material is paramount. The most potent instrument of education is still the personality of the teacher.

CHAPTER V

THE NEEDS OF SOCIETY

We cannot live by ethics alone. Our life is spent in the disposition of our resources, either wisely, to the satisfaction of our needs, or foolishly in waste and dissipation. What is true of our private resources of time, talent and energy is also true of our national resources: the accumulated knowledge of those who have gone before us, and the substance of the earth we inhabit. It is the efficient distribution of inherited knowledge among the rising generation that is one of the primary problems of education, and it is the wise use of material resources that is in the forefront of the problems of government. It must not be thought that the government of a people is solely that vested in the High Court of Parliament or its equivalent. The wide powers of local governments are well known. The captains of industry, editors of great newspapers, heads of advertising firms, service chiefs, originators of great enterprises, and all those who wield power over men or matter, can be said to govern in greater or less measure, in that they control the actions of their fellow men and direct or influence the disposal of the resources of the community. Such men as these, who shape the destiny of others, can be seen in the long run to have led a people to prosperity and greatness, or to have allowed that people to sink into the slough of mediocrity. Not only would their decisions frequently have been different had they possessed a knowledge of science, but their whole mental outlook would be more in touch with the world as it is, if their mental habits had been formed by the interplay of scientific ideas with their normal utilitarian interests.

There is much to be said for the feeling of pride and well-being that arises in a man who is conscious that he is

a member of a great community, the history of which is adorned with great names and with the records of great deeds. Such a man will not care to have it said that it was in his generation that a decline in the national fortunes began, or that through feebleness of vision, or love of ease, or waning energy, his country faltered in the race and was left behind.

There is to-day no lack of realisation of the part which science must play in the civilisation of the near future. Sir Henry Dale, the President of the Royal Society, in appealing for a worthy building in which to house the headquarters and libraries of English science, wrote recently, "It is upon scientific discovery that the achievement of the new social aims must count."[1] Commenting on this letter, a *Times* leader writer, in summing up the opinions of many of those whose positions should qualify them to judge, said, "Modern civilisation is permeated by science." This is the case in both war and peace. Those who frame policies or plan enterprises or conduct the business of communities must understand this fact and must include it in any provisions they may make. At present many people in responsible positions know only the bare results of scientific work, the mere application of its principles to problems of everyday life and the use of those foolproof devices which are too common to need enumeration, without any realisation of the sources of the materials they use so heedlessly, or the effect of mechanism on the health and happiness of their fellows. Only a carefully planned educational system, which is designed to explain and to correlate the achievements of science, and to enlarge the mind with a vision of what may be possible to-morrow, can adequately equip clever and energetic young people for the tasks that lie ahead, when they come to take their places in the hierarchy of government.

It will be found that in any age certain men emerge by reason of their enterprise in politics or business. Their

[1] Dale, Sir Henry, when President of the Royal Society: in *The Times*, Dec. 1st, 1943.

mental habits, in so far as they conform to Jung's classification, would justify their inclusion among people of the extravert intuition type. They are alert and ready to learn the details of what they conceive to be their business. In our day, they should be told that science is their business. Children who are potentially of this type should receive special treatment. When their mental habits have become sufficiently stabilised to justify classification by those who know them well, or by suitable tests if such tests exist, so that the kind of contribution that they can make to the life of the state can be recognised, they should be introduced to those wide-embracing generalisations known as the great theories of science. The principles of conservation, the atomic theory in its modern form, the electro-magnetic theory of radiation, the principles of heredity, and an outline of physiology, should constitute the minimum of equipment with which a legislator or an administrator should start. The more inquisitive among them will fill in the outlines for themselves by private reading and in other ways, and will thus be able to make intelligent use of expert advice.

It now becomes apparent that in addition to science as a fourth R, in which certain of the elementary scientific notions are made available to all, there is a considerable class of persons, constituting one of the most important sections of the community, who require a wider and more detailed course in general science, but still without that concentration on technique which is necessary for those who are to contribute to the advance of science on its technical or theoretical sides.

At what stage this is done and what pupils are selected for such instruction will have to be decided in the light of general educational policy. It is possible that the course would be of value to all pupils, but if insufficient teachers with adequate qualifications can be found, it might be satisfactory at first to rely on an assessment of the psychological type of pupil who would profit most by it, by some form of objective test, or otherwise.

There are two ways in which this second stage of scientific education can be carried out. One is by means of films, each of which, perhaps, should be shown twice, before and after an account of the subject has been written by the pupil; the film provides, first, a presentation of the subject and then affords an opportunity for a comparison of the actual state of the case with the student's version of it. Much progress in the making of scientific films for educational purposes was made during the war years, and the experience gained will prove to be most valuable now it is possible to concentrate on the requirements of general science at the level that is here intended.

The second method of scientific education for this class of pupil is by means of lectures which are amply illustrated by experiments and diagrams. Special demonstration apparatus will have to be designed, on a large scale if large classes are to be instructed, or perhaps certain cases can be met by the projection of a magnified silhouette of the apparatus on a screen. The value of this method is that small movements can be made visible to a large audience. Teachers who are entrusted with this work will have to possess experimental skill in addition to other qualities. As well as having powers of succinct and clear presentation, which is the *sine qua non* of teaching, there should be a touch of showmanship. It is the dramatic quality of an episode that plants it firmly in the memory.

There is obviously a wide field for enterprise in this connection. Courses of instruction will have to be planned, apparatus will have to be manufactured, and much explanatory literature will have to be written and distributed. That all this can be done if the need is recognised as urgent was shown in the Services during the recent war. The problem of explaining comparatively complicated mechanisms to recruits, many of whom had no previous knowledge or experience of the subjects, was efficiently carried out by the use of diagrams, models, and instruction books, which supplemented the spoken word of the instructor. It is true that Service teaching was mainly concerned with the

operation and maintenance of mechanism, but once simple mechanisms have been understood, (and it is here that the fourth R contributes to the requirements of later education) the more recondite principles of science can often be illustrated by analogy, for, it will be remembered, the theories of science are acceptable only in so far as they serve to explain the unknown in nature by analogy with that which has already been experienced.

For most of the work discussed so far, lecture rooms alone are necessary, although there must be good-sized preparation rooms, workshops and store-rooms in which the demonstration apparatus can be fitted up, repaired and kept out of harm's way when not in use. Laboratory buildings are far too frequently ill-equipped in these respects.

If it is thought advisable that pupils in either of these two elementary stages should devote some time to the handling of apparatus for themselves, suitable rooms must be provided. For those who do not intend to specialise in any branch of science, it can perhaps be argued that practical work is a waste of time and money, but unless all are given the opportunity of showing whether they have any aptitude for laboratory manipulation, it will not be possible to be sure that the maximum use has been made of the scientific talent that a community contains. On this ground alone it is strongly urged that some simple exercises in physical, chemical and biological manipulation should be carried out by all children. Those with no aptitude, or with a distaste for this kind of work, will not be required to spend very much time upon it, but they will have had the useful experience of an initiation into the kind of work that is done by their scientific brethren.

The important thing about laboratory accommodation, once it has been provided, is that it should be used to the full. All science is founded on experiment and observation. It is in consequence a gross misuse of the facilities afforded by a laboratory to employ it continually for descriptive lecturing or mathematical exposition. Any classroom will do for this kind of work. A laboratory should be perpetually

untidy with apparatus that is in use. Arrangements should be made for those that are interested in practical science to use laboratories whenever the time for doing so can be found.

Many voices have been raised of late with proposals for an intensification of scientific research in industry. This is doubtless due to a fear that, now that the war is over, this country, which was once pre-eminent in industry and manufacture, will fall into a position of insignificance beside those other great countries that have more recently turned their resources and energies to the large-scale manufacture of goods of all kinds. This fear is reasonable and well founded. Having been first in the field, we have certain handicaps in industrial organisation to overcome, notably the continued use of cramped and unsuitable premises for manufacturing processes, which are often located in crowded districts where expansion is difficult; also the expense of improving the factory lay-out is often unwelcome. Another factor is the independence of mind of the owners of some small businesses, for these men often prefer to go their own way rather than to profit by the experience and advice of others. Nevertheless, there is a strong movement on foot for the provision of many more research laboratories in industrial works, or for their endowment at suitable centres so that the works can submit their problems to these centres for solution.

It is well known that much money has already been spent on research in industry in this country. The argument is that much more, in proportion, is being spent in other countries, and that we must follow suit. The Department of Scientific and Industrial Research has been in existence since 1915 and is empowered nowadays to spend a sum of the order of one million pounds annually. Its work is not concerned so much with the special problems of industry as with those departments of life which affect us all but which are not specifically the concern of private persons or of companies which are trading for profit. Examples of these departments are those of Food Investigation, Forest Products Research, Road Research and Water Pollution

Research. The National Physical Laboratory is also under the Department.

In addition to the Department, there are two other research organisations supported by the Government, the Agricultural Research Council and the Medical Research Council. There is also the Executive Council of the Imperial Agricultural Bureaux, with its ten research institutes and stations, financed from a common fund provided by the governments of the Empire.

The particular problems of industry are usually solved by the research organisations which either belong entirely to the firms concerned, or are supported by a group of firms. The results of such research are often kept secret, at least for a time, which is contrary to the practice of pure science, but which is a perfectly reasonable course of conduct for a commercial firm or group of firms who have undertaken the cost of the research. The results of the research are their property. Even so, there seems to be a tendency in the U.S.A. towards the pooling of the results of research among industrialists, on the presumption that that which adds to the prosperity of the community as a whole will ultimately benefit the initiating firm. Perhaps in this country about a million pounds a year is spent on industrial research of this kind, part of which is a contribution from government funds.

No one can say just how much money should be allotted to industrial research, whether the money is forthcoming from the Government or from the firms, but it is certain that the firms could spent very much more than they do and that they would profit thereby. The Government could assist by remission of taxation on genuine capital expenditure on research, as well as on maintenance and running expenses. This question of the annual sum to be expended on research must depend in part on the competitive situation, that is to say, on how much is being spent by other countries on the manufacture of those products which we wish to make in this country, and in part on the nature of the problems which are to be solved. Sometimes a satisfactory solution of an industrial problem is reached comparatively quickly

and the matter is done with, but with most of the problems on which research is required in industry, such as research into the most economical way of using our fuel resources, or into the best way of making the various grades of steel required for different purposes, there seems to be no end to the problem when its changing nature and all its ramifications are considered.

It is only by an understanding of the method of science and of the nature of research that an intelligent judgment can be made on the question of the amount of money that can reasonably be spent on the solution of a particular problem. The results of research may be very slow to emerge, that is to say, there is usually a considerable time-lag between the starting of a research and the collection of any profits that may accrue from it. Directors of firms should understand this and should be prepared to face the fact that no profitable results can be guaranteed from any given research. To what extent enlightened shareholders can educate their directors has not yet been determined, but there would be obvious advantages to British industry if the education of its directors in this respect were unnecessary.

The situation is clearly put in the terms of a motion tabled in the House of Commons in November 1943. The motion was as follows:

"That this House, recognising that if the United Kingdom is to maintain its position in the post-war world and carry out effective plans for physical reconstruction and social betterment, research and the application of scientific knowledge in all fields must be promoted on a far bolder scale than in the period 1919–39, urges His Majesty's Government forthwith:

(1) To assure the universities that in planning future developments for research, teaching, and higher learning as a whole they will receive support from the State on a much larger scale than hitherto.

(2) To arrange that education and training in schools, technical colleges, and universities shall be directed at the

earliest date towards providing a far greater number of persons highly trained in science and technology.

(3) To set in motion schemes to ensure a substantial and co-ordinated expansion of research activity by private firms, co-operative industrial research associations, and State and other research establishments; and to this end, to provide assistance by adjustment of taxation, by more generous financial grants and through adequate priorities both in demobilisation and for materials required for building and equipment."

The requirements are comprehensive. To what extent can the resources of our educational machinery supply them? There will clearly have to be a much greater allotment of time for the teaching of science in schools. This scientific work will have to be of two kinds (*a*) general descriptive science for all pupils, and (*b*) more detailed work, including quantitative determinations and the foundations of technique, for the large body of specialists who will undoubtedly present themselves for instruction.

At the meeting of the British Association at Dundee in the autumn of 1947, the subject of the education of the man of science was discussed. Dr. Eric James, the High Master of Manchester Grammar School, said: "The task of the schools is thus a threefold one: first, to maintain the quality of the specialist knowledge of our potential scientific workers; second, to see to it that they are aware of the social relevance of their work; and third, to ensure that they are people with the fullest general education."[1] If this enlightened policy can be put into effect by rearrangement of a curriculum which is already crowded, a long step towards an ideal education will have been taken, and the reproach of Philistinism which is sometimes levied against the scientist will no longer be justified.

The two main branches of science are physics and biology, but all students should be grounded in (1) mechanics, (2) the properties of matter, and (3) energetics, that is to say, the forms of energy and their interconversion.

[1] Reported in *Nature*: 18th Oct., 1947.

Work in chemistry, biology, or the special branches of physics should be carried on simultaneously, according to the bent of the student. This system, which does not differ greatly from current practice in well-conducted schools, has not failed to produce workers of good quality, but has not produced them in sufficient numbers for our needs. No special steps need to be taken to find recruits for research in pure science. Those who have the talent and the interest to engage in such work are comparatively few in number, but this country has provided some of the most illustrious names in the whole history of science and, although it is more difficult to attain pre-eminence nowadays than it was when there were fewer workers in the field, our national contribution to the advancement of academic science during the present century compares favourably with that of other countries. The great research worker in pure science is markedly of the extravert thinking type as a rule. He is unlikely to be deflected from the way of life he has chosen by the promise of power or the lure of gain. His reward cannot be computed and is imperfectly understood by men of other types, but it is sufficient for him.

Those with good scientific ability but who are not required for research in pure science, can usually be persuaded to turn their talents to the solution of more immediately practical problems. They constitute the class to which industry must turn for its research workers, and if there are not enough of them, a number of those of less decided mental habit who nevertheless possess in some measure a tendency to the extravert thinking type must be lured within it, by the promise of a reasonable measure of satisfaction and security. There has not been in the past decade or two a deficiency of industrial scientists. Rather, there has been a dearth of employment for them and, too frequently, only the promise of a miserable wage for those who found employment.

No new problems in education arise here, except those concerned with the expansion of existing educational facilities. The new problem is that of education for the higher direction of industry: for the enlightenment of those

who decide its major policies: for the inculcation of foresight and wisdom in those who make far-reaching decisions: for the stimulation of invention and its application to industrial problems: and, above all, for driving home a realisation of the trends and possibilities of scientific development. It is enterprise and inventiveness that are required. These characteristics are to be found particularly in the intuitive extravert, and the full use of the manufacturing potential of this country will only be made when the intuitive extraverts possess a background of scientific knowledge. Undoubted examples of the type or those who show a leaning towards it must be recognised in childhood and encouraged to employ their energies in invention and design. If they can be interested in science and made to realise that therein lies a suitable field for the employment of their talents, our products should no longer fail in originality or ingenuity in comparison with those of the U.S.A. or Germany or Japan. The undoubted need for this kind of enterprise in manufacture is one of the strongest arguments for an extension of the teaching of science in schools, for the relatively undifferentiated material which constitutes a large proportion of the school population will in general turn towards that career which offers the richest rewards. It is precisely in the field of enterprise that the largest opportunities lie. It may be said that the mere inventor is not as a rule a highly paid person. This is true; but there is no dearth of inventiveness among our people, and if the need for invention were realised by the directors of industry, the status of the inventor would be raised. There would be a great demand for the services of the most prolific and ingenious inventors. The development of industry along these lines will demand special qualities from its directors, as has been stressed above. We must somehow produce in sufficient quantity men who are not only capable of inspiring others to do their best work and of co-ordinating and directing that work along lines of fruitful endeavour, but who are far-sighted, well-informed opportunists, with their fingers on the pulse of to-morrow.

CHAPTER VI

THE RELATIONS OF SCIENCE WITH WAR, RELIGION AND ART

THESE tremendous subjects can neither be ignored with impunity nor can they be examined without running the risk of giving offence, but if science as a social force is to take the leading place in human affairs which is widely foreshadowed, it is important that an objective view of the relations of science with other modes of human conduct should be given; a view from which an effort has been made to remove all personal emotional bias and which it is hoped has been presented here with sufficient detachment to avoid hurting the susceptibilities of the reader.

Science and War. War is not a new phenomenon, nor is a particular scientific discovery more than an occasion for an outbreak of war. The causes of war lie deeper: they are to be found in the human spirit. On reflection, it can be seen that there is not very much more sense in saying that science is a cause of war than in saying that music is a cause of war. The writing of the *Marseillaise* did not cause the Napoleonic wars, nor did *John Brown's Body* cause the American Civil War. Science and invention are modes of human conduct, just as the making of music is, and in the cause of self-preservation during time of war these modes of conduct are exercised and directed towards the desired end, which is the defeat of the enemy. In peacetime there are always some men who have an eye to the future and who devote themselves to elaborating warlike devices, whether they are designing guns or writing military marches; it is as well that there are such people among us until all nations simultaneously foreswear the arts of war and can be relied upon not to take up arms again against their neighbours.

The completion of the nitrogen fixation plant in Norway in 1914 can hardly have been a cause of the German war of 1914–18, although it may have influenced the time of its onset. So it was with the second German war. A nation bent on war, for whatever purpose, if that purpose is seriously and wholeheartedly entertained, will, in order to further its interests, make use of every expedient of military value that comes to hand, including the discoveries of science. But the aim of science is the understanding of natural phenomena, not the imposition of the will of one nation on the people of another. The accompaniments of science are knowledge and mastery over nature, not destruction, fire and pestilence. Gigantic wars were fought before science was born. Many were fought during its infancy. The campaigns of Xerxes, Alexander, Attila, Genghis Khan and Napoleon have not been attributed to scientific invention. They were not perhaps global wars in the modern sense, but the earlier warmakers used whatever weapons and means of transport were available and frequently contrived to overflow from one continent into the next. Past wars were accompanied by fire, famine and pestilence on a scale hardly inferior to the horrors of to-day. Whoever may have started these or any other wars known to history, or may have provoked them, it was not men of the thinking type. The pure scientist must be acquitted of such a charge.

It is often said that the invention of the aeroplane, which is loosely thought to be one of the achievements of science, whereas its development is at least as much an achievement of man's kinaesthetic skill, is the greatest scourge that has ever befallen humanity. The same may well have been felt by primitive man about the domestication of the horse and its use in war. Horses were swift; an unsuspected descent could be made upon the enemy by means of them. Their riders carried weapons with which they not only slew or wounded one another, but were quite capable of launching missiles against unmounted troops, or of riding them down. Even civilians could be rounded up by means of horses and carried off into captivity. In addition, the horse was

invaluable for carrying munitions and all the supplies of an army. The parallel is almost complete, but to-day the horse is called the friend of man. What is the aeroplane but one of his tools? The recent discovery of methods of converting matter into energy on a large scale is not a case of a different kind. It is certainly more menacing and more alarming than any previous discovery or invention, but a controllable rocket containing an atomic bomb is still a weapon, to be used or not used, as folly or good sense dictates. The question of whether men can be compelled or frightened into amity is still *sub judice*, and will not be further debated here. It may be said that what science has done is to change the style and impedimenta of war. Science has aggravated war and has dragged more people into it. But, if good sense should chance to prevail, the aeroplane and nuclear fission may be counted in the near future among our blessings. Even the guided rocket may perhaps be turned to good account.

Science and Religion. The growth of science has eliminated the necessity for religions to make pronouncements on matters of fact. The function of religion is now to present suitable material for belief about the attributes of a deity and to organise the worship of that deity in a manner which is found to be helpful to the devotees of the religion. A third legitimate function of a religion is to give guidance on matters of conduct. The method by which a religion exercises these functions is mainly by emotional stimulation, but informative language is also used, as indeed it must be in human communication, although care should be taken to distinguish the informative language of religion from that of science. A statement may be couched in the form of scientific prose and may have the appearance of truth in the sense in which "truth" is used in science, but if the statement is founded not on the observation of nature, but on belief, it is not a scientific statement, in spite of the form in which it has been cast.

It was the appropriation by science of the right to make pronouncements on natural facts which has led to what is

often called the conflict between science and religion. A good deal of heat was shown by both sides. The men of science found themselves in a position to make statements about nature which were of a high degree of probability and which quickly gained acceptance by unbiased people who were capable of understanding the evidence for them. Some of these statements were contrary to orthodox belief. The only wise course for those interested in the maintenance and spread of religion was to admit that some of its utterances had been hypothetical or symbolic or provisional, with emotional rather than factual significance, and to withdraw from a field of inquiry for the investigation of which they were not equipped. This ideal position has not yet quite been reached, although it is realised in some quarters that its ultimate attainment is inevitable. There is thus no permanent reason for a conflict between science and religion, for they use different methods and are concerned with different things. There is to-day no overlap or common ground between them, but because of a lack of understanding of their respective functions and methods, much confusion exists in the minds of uninformed people as to their spheres of action.

It is precisely because so many scientists belong to or nearly approach to the extravert thinking type that they do not perceive the appeal of religion so strongly as do the types who allow fuller play to the emotions and even find their deepest pleasures in emotional situations. The thoroughgoing extravert thinker is almost continuously absorbed in the solving of problems by intellectual means, and has not very much residue of time or energy for the exercise of the functions of feeling, sensation or intuition. On the whole, emotion is repressed by scientific thinkers.

It is in a controversy between the upholder of a religious faith and a scientist that confusion is likely to arise, because the two parties to the controversy can hardly avoid using the same words in different senses. The key word in this connection is "truth". Both sides claim to have arrived at "truth" or to be capable of doing so. The "truths" of

religion are attained by revelation or intuition, and when adequately apprehended by a religious person, may prove to be either the mainspring of a life devoted to the service of others or the agents which resolve the conflicts of a troubled mind. This use of the word "truth" has the merit of efficacy and the sanction of time, but it has no connection with factual truth of the kind investigated by science. The "truths" of religion are subjective and are not made objective by the addition of the further emotive term "absolute". When the word "truth" is used with emotive significance, as is so often the case in religious speech or writing, it may be expanded to "intuitive truth" in order to distinguish its emotive from its informative use. The "truths" of science are objective and are not invalidated by being called "mere inductions". They are known to be probabilities, often of a higher order, and may be distinguished from dogmas by the expansion "inductive truth". That a single word should have to do duty to refer to two such utterly different conceptions is unfortunate, but, if there is any blame to be apportioned for the confusion that has resulted, it should perhaps be laid upon science, which has adopted a word already in use to describe something technical, instead of coining a new one of its own. A concise word is required for the referent contained in the phrase "probability of a high degree as assessed by the method of science". This is what a scientist means by scientific truth. Had science invented a term of its own for this notion, there would still remain the possibility of confusion between the intuitive truth of religion and the factual truth of everyday life. It should be one of the functions of education to see that no young person who is capable of grasping a distinction of this kind is allowed to continue in ignorance of it.

Science and Art. Man's creative impulse has shown itself in a variety of constructive actions, some of the products of which may be called works of art. Usually a technical discovery or invention of some kind has made possible the development of a particular art. Thus, the invention of

writing gave a great impulse to the art of literature, the enormous expansion of which has been due to the further invention of printing by means of movable types. The discovery of counterpoint is said to have been fundamental in the development of Western music, and the successful search for pigments and for suitable surfaces to which they could be permanently applied has given us the art of painting. So great has the appeal of the products of these inventions proved to be, that the further development of the arts has been adopted as a way of life by many men to the exclusion of the more usual careers of commerce, politics or agriculture; these men are of the introvert sensation type and, by the exercise of talents which are not shared by all their fellows, they seek to satisfy their innate desires. Such men are artists. From an examination of their work, much of which has been preserved and can therefore be judged by their posterity, we are able to form the opinion that some of those who devoted themselves to the arts must have been endowed with the highest talents: for when we, who, perhaps, may claim to possess such talent, attempt the composition of a symphony or the painting of a picture, we find our efforts fall miserably short of theirs.

Further, the evidence seems to show that the various arts have developed from small beginnings over a number of years, often simultaneously in several different countries, and, by a kind of *crescendo* of progress, have reached such a pitch of excellence in the hands of their greatest exponents, that we stand amazed at the magnitude of their achievements and can only ask what greater masterpiece can follow. There comes a time when an anticlimax is inevitable. After a period of the greatest brilliance in artistic achievement, lasting, perhaps, for a hundred years or so, there comes a decline. New masterpieces are less and less able to command the eulogies of the honest critic. Several writers have detected something of this kind in the history of art. In *Erewhon*, Samuel Butler has this passage: "I know not why, but all the noblest arts hold in perfection but for a very little moment. They soon reach a height from which

they begin to decline, and when they have begun to decline it is a pity that they cannot be knocked on the head; for an art is like a living organism—better dead than dying. There is no way of making an aged art young again; it must be born anew and grow up from infancy as a new thing, working out its own salvation from effort to effort in all fear and trembling".[1] The Oxford philosopher, R. G. Collingwood, writes: "To the historian accustomed to studying the growth of scientific or philosophical knowledge, the history of art presents a painful and disquieting spectacle, for it seems normally to proceed not forwards but backwards. In science and philosophy successive workers in the same field produce, if they work ordinarily well, an advance; and a retrograde movement always implies some breach of continuity. But in art, a school once established normally deteriorates as it goes on. It achieves perfection in its kind with a startling burst of energy, a gesture too quick for the historian's eye to follow. He can never explain such a movement or tell us how exactly it happened. But once it is achieved, there is the melancholy certainty of a decline. The grasped perfection does not educate and purify the taste of posterity: it debauches it. The story is the same whether we look at Samian pottery or Anglian carving, Elizabethan drama or Venetian painting. So far as there is any observable law in collective art-history it is, like the law of the individual artist's life, the law not of progress but of reaction. Whether in large or in little, the equilibrium of the aesthetic life is permanently unstable."[2]

That there are new and vigorous movements in the arts is undoubted. In their attempt to scale new heights the moderns are not trying to continue in the style of their great forerunners. Whether or not they could do so, if they tried, is beside the point. They are in fact doing something different. Their emotional and intellectual environment has changed, and their achievements must be assessed not by their inexpert contemporaries, but by posterity.

[1] Butler, Samuel: *Erewhon*, p. 114 (Penguin edition).
[2] Collingwood, R. G.: *Speculum Mentis*, p. 82.

It is not denied that the artist has a necessary and valuable contribution to make to life in the societies of to-day. As long as cities are inhabited the architect will flourish. As long as nature and the human scene persist, there will be those who will delight to record them in painting, in statuary, or in verse. But there is a feeling abroad that these things have been done so nearly perfectly in the past that no further improvement along traditional lines is probable. The technical and aesthetic problems which confronted the great masters have been solved. Those who continue to work along the same lines achieve only repetition with variations, for when a problem has been solved, the joy of creative striving fades, only to be replaced by the minor satisfaction of a routine task faithfully carried out. Even if this thesis is unacceptable to the reader, let us consider the bearing of such a belief on the position which science holds to-day.

The sum of those achievements which go to make up what may be called the total volume of art, represents an enormous expenditure of directed and constructive human energy. Men of the highest intellectual power, men standing head and shoulders above their fellows by reason of the richness of the talents with which they were endowed, have chosen the pursuit of the arts before all other careers as a source of satisfaction for their psychological needs. It would not, perhaps, be too fanciful to say that no inconsiderable part of the stream of human energy, at any rate in the West, has been concentrated from time to time upon the solution of the problems with which artists have found themselves confronted: problems which are as various as the arts to which they belong, but whose origins can be traced, broadly speaking, to an innate desire to satisfy the constructive and aesthetic impulses. We may say that there have been occasions when a confluence of human personality towards the introvert sensation type has taken place, a kind of concentration of talent in a particular channel, which has brought forth the golden ages of the arts.

It has been suggested above that the greatest of those in whom the constructive and aesthetic impulses were most

strongly developed, have, to a large extent, solved the various problems raised in the various arts. Although the tasks have been completed, the stream of human energy has not ceased to flow. Ability has not noticeably diminished. Since the great artists flourished, and even while they flourished, there have been other men of peerless intellect, whose mental endowment was in no degree inferior to that of the greatest painters, poets and dramatists of the golden European age, and who, like the great artists, have sought first neither power nor riches, but have found their reward in the creative lives they have led and in making their unique contributions to the sum of human achievement. These men are scientists: Galileo and Newton; Faraday and Clerk-Maxwell; Pasteur and Koch; Rutherford and Einstein. Jointly, they too, like the artists, have constructed a picture, not indeed a representation of Nature as she appears to be to the outward eye, nor a picture of the spiritual aspirations of man, but a diagram of the workings of Nature as manifested in the stream of physical events in which we are all inescapably immersed.

Although the artist and the scientist belong to different psychological types, it is possible to trace certain common factors which determine their modes of life. It is as though different patterns of fabric, made for different purposes and by different means, were to be woven out of the same threads. The very diversity of the products conceals the common origin. Given the underlying human material, what seems to change is the distribution of ability among the types and the driving force behind the exercise of ability. When there is some ideal at which to aim, some great problem to be solved, it appears that the concentration of interest on one theme may induce a great effort in one direction, such as that of painting or science or literature or mathematics or religion, with the consequent unleashing of a great stream of energy in one direction and an inevitable simultaneous damping down in other creative fields. At present the stream of energy is directed towards the solution of scientific problems.

The elements which are common to science and to art have been clearly diagnosed by Professor Samuel Alexander, who held that the constructive impulse is to be found in both the artist and the scientist. He writes: "The constructive instinct becomes artistic when it ceases to be practical."[1] It has already been said that pure science cannot be regarded as having a practical aim, but a word of warning is necessary. It is not denied that either art or science makes use of a practical method to achieve its aim. The sculptor wields a chisel, the painter a brush, the poet a pen; and to the extent that artists pursue their art by these means they are using a practical method; but the artistic activity taken as a whole is an addition to the essentials of practical living. It is with a practical aim in view that we grow a crop of food or construct a ship. The food is for consumption, not for contemplation, and the ship is made for the practical purpose of carrying a cargo. Those who work at pure science have no such practical aim. They may be said to want to know because it is pleasing and satisfying to know. They do in order to know, but the practical man wishes to know in order to do. For the man of science, to know is an end in itself.

Professor Alexander then goes on to discuss the aesthetic emotion. He writes: "The aesthetic emotion is the emotion proper to the aesthetic impulse and contains many elements blended into one corresponding to the various elements of the impulse itself. There is the predominating element of sheer constructiveness, the delight of making; there is the element of synthesis or the constructional element, that of composition; and there is the sensuous pleasure of the material, in poetry the mere pleasure, improperly called beauty, of the words as sounds, and of the images they convey, as well as the added pleasure of metre and rhythm and rhyme which partly trench upon the pleasure of the composition. The constructional element or composition is shared by art with science and morals, and is thus not distinctive of art."[2]

[1] Alexander, S.: *Art and Instinct*, p. 16 (Clarendon Press).
[2] Op. cit., p. 17.

Let us grant that the constructive impulse is common both to the artist and to the scientist. We have yet to show that the other impulse of the artist, the aesthetic impulse, has its counterpart in the mental disposition of the man of science. The work of the artist is, in part, the expression of his experience of the aesthetic emotion. It is reasonable to suppose that when he has finished a piece of work and contemplates it, the impulsive desire which drove him to complete the work is, at least for a time, satisfied. He has been compelled by forces, which perhaps he cannot diagnose, to take a particular course, and when the driving force is spent and he has reached his goal, he is for a time at rest. We cannot here undertake to analyse the actions of the creative artist and of the creative scientist in full, nor to show, if it is possible to do so, that there may be a point-to-point correspondence between each step of their psychological procedure. But there are many cases on record of the ecstatic delight which scientists have felt in the discoveries they have made or in the contemplation of a new effect which they have brought into being. Kepler has left a record of his emotional reactions at the time of the discovery of his laws. Davy, and in a different way, Faraday, were emotionally affected by their successful work. There is intense pleasure to be derived from the production of certain physical phenomena, particularly if the search has been long and arduous and success has eluded our earlier efforts. Who can doubt but that an emotion akin to the aesthetic emotion must be felt by him who works towards establishing a quantitative law of nature, and finally triumphs over all the difficulties he has met? Perhaps his whole being is keyed up with excitement as his work approaches its conclusion. Is it a law of nature which he has found, or is there some further puzzle to be solved? Dramatic moments often occur during a laboratory research, but the investigator must never allow his feelings to obtrude themselves to the extent of clouding his scientific judgment.

Some scientific theories can be compared favourably with the greatest of literary compositions. Imagination,

ingenuity and insight, not into human nature but into Nature herself, are essential constituents; in fact, a theory in its final form may have a completeness and a comprehensiveness which are reminiscent of the greatest works of literary art. Critics of scientific theory have sometimes forsaken scientific prose and have used all the emotive terms at their command in praising the work of such men as Newton, Faraday and Clerk-Maxwell. This is not to say that the extravert thinking type can be identified with the introvert sensation type or that in the most extreme instances they have very much in common. All that it is intended to maintain is that successful exercise of the constructive impulse can give rise to a subjective satisfaction in both types, although the operations of the scientist on the one hand have been guided by thought, and those of the artist on the other hand have been guided by sensation. The scientist cannot afford to allow himself to be susceptible to emotion in the course of his constructive work, but he is very well capable of enjoying success when it comes to him and of suffering disappointment when he finds that his work has been in vain.

For want of a better simile, we have referred to the immense artistic output of the past as having been the product of that part of the stream of human energy which is directed, not towards a practical end, in the sense that commerce and government are directed to practical ends, but towards the satisfaction of aesthetic desires. This stream of energy would seem to have accomplished, at least qualitatively, all that was possible with the material at its command. But the stream is not exhausted. It has been diverted into a new channel. The volume of material upon which it can now work is far greater than hitherto: the problems which confront it are more numerous and more complex. Much progress has already been made in ordering this material and it is becoming apparent that a fruitful method of attack has been discovered; for just as the products of the artist are judged to be successful when they are put to the practical test of satisfying the aesthetic desire, so the laws of science

are only adopted when they have been put to the test of practical verification.

Scientific creation has replaced artistic creation as a world movement. Science is the modern substitute for art, in the sense that it requires creative energy of the same kind as that which gave us art. Those with great synthetic or integrating powers no longer turn to art as the medium in which their creative strength may profitably be exerted. There is a more attractive field of endeavour open to them. Men endowed with the highest talents no longer explore the possibilities of the different art forms: instead, they employ the scientific method to explore Nature's secret paths. It is felt that a challenge has been set by Nature which is worthy of the human mind. The challenge has been accepted and man must wrest as many of her secrets from her as Nature can be made to yield. More than three hundred years have passed since Galileo worked upon the problem of motion. More than two hundred years have passed since Newton died. Great men have come and gone and have added their quota to the sum of scientific knowledge, leaving us their laws, their theories, and their technical inventions. In time of peace, pure research is carried on in almost every city of every continent, but the great unifying minds are few. We are awaiting the birth of another Newton.

INDEX